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JOSEPH STANLEY-BROWN, *Editor*

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PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues a single serial octavo publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former embracing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing larger papers accepted for publication. The matter is issued as rapidly as practicable, in covered brochures, which are at once distributed to Fellows and to such exchanges and subscribers as desire the brochure form of distribution. The brochures are arranged for binding in annual volumes, which are elaborately indexed. To this date eleven volumes have been published.

The Bulletin is sold to Fellows of the Society and to the public either in separate brochures or in complete (unbound) volumes. The *prices* are as follows: To libraries and to persons residing outside of North America, five dollars ($5.00) per volume; to persons in North America, not Fellows of the Society, ten dollars ($10.00) per volume (the same amount as the annual dues of the Fellows); to Fellows of the Society, a variable amount, depending on the cost of publication. These prices cover cost of transmission to all parts of the globe. No reduction is made to dealers. Subscribers should specify whether they desire the brochures or the completed volume. Orders should be addressed to the Secretary, and drafts and money orders made payable to the *Secretary of the Geological Society of America*, Rochester, New York.

Description of the published Volumes

Volumes.	Pages.	Plates.	Figures.	Price to Fellows.
Vol. 1, 1889	593 + xii	13	51	$4.50
Vol. 2, 1890	662 + xiv	23	63	4.50
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Vol. 4, 1892	458 + xi	10	55	3.50
Vol. 5, 1893	665 + xii	21	43	4.00
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Vol. 7, 1895	558 + x	24	61	4.00
Vol. 8, 1896	446 + x	51	29	4.00
Vol. 9, 1897	460 + x	29	49	4.00
Vol. 10, 1898	534 + xii	54	83	4.00
Vol. 11, 1899	651 + xii	58	37	4.50

Brochures of Volume 11

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Proceedings of the Eleventh Summer Meeting, held at Columbus, Ohio, August 22, 1899. H. L. Fairchild, *Secretary*	1- 14	....	....	$0.15	$0.30
Geology of Oahu. C. Hitchcock. With notes on the Tertiary geology of Oahu. W. H. Dall	15- 60	1- 8	....	.75	1.50
The tetrahedral earth and the zone of the intercontinental seas; Annual address by the President, B. K. Emerson, with an appendix. The asymmetry of the northern hemisphere. E. Suess	61-106	9-14	1-7	.75	1.50

Brochures.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Upper and Lower Huronian in Ontario. A. P. Coleman	107–114	....	....	$0.10	$0.20
Volcanics of Neponset valley, Massachusetts. F. Bascom	115–126	....	....	.10	.20
Geology of the Wichita mountains. H. F. Bain	127–144	15–17	1–7	.35	.70
Relative ages of the Kanawha and Alleghany series as indicated by the fossil plants. D. White	145–178	....	1–3	.35	.70
Enrichment of mineral veins by later metallic sulphides. W. H. Weed	179–206	....	....	.30	.60
Fault scarp in the Lepini mountains, Italy. W. M. Davis	207–216	18–19	....	.20	.40
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Relations between the Ozark uplift and ore deposits. E. Haworth	231–240	....	....	.10	.20
Lower Devonic aspect of the Lower Helderberg and Oriskany formations. C. Schuchert	241–332	....	....	1.20	2.40
Silurian-Devonian boundary in North America. H. S. Williams	333–346	....	....	.15	.30
Siluro-Devonic contact in Erie county, New York. A. W. Grabau	347–376	21–22	1–8	.35	.70
Jurassic rocks of southeastern Wyoming. W. C. Knight	377–388	23	....	.30	.60
Igneous complex of Magnet Cove, Arkansas. H. S. Washington	389–416	24	1	.45	.90
Some coast migrations, Santa Lucia range, California. B. Willis	417–432	25–29	1–2	.35	.70
Glaciation of mount Ktaadn, Maine. R. S. Tarr	433–448	30–39	....	.50	1.00
Vertebrate footprints on Carboniferous shales of Plainville, Massachusetts. J. B. Woodworth	449–454	40	1–2	.25	.50
Glacial origin of older Pleistocene in Gay Head cliffs, with note on fossil horse of that section. J. B. Woodworth	455–460	41–42	....		
Thomsonite, mesolite and chabazite from Golden, Colorado. H. B. Patton	461–474	43–49	....	.40	.80
Cambro-Silurian limonite ores of Pennsylvania. T. C. Hopkins	475–502	50	1–7	.35	.70
Contact metamorphism of a basic igneous rock. U. S. Grant	503–510	....	....	.10	.20
Proceedings of the Twelfth Annual Meeting, held at Washington, D. C., December 27, 28, 29, and 30, 1899, including Proceedings of First Annual Meeting of the Cordilleran Section, held at San Francisco, December 29 and 30, 1899. H. L. Fairchild, *Secretary*	511–651	51–58	....	2.00	4.00

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a Memoir receives 30 copies without cost, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of volume 11 have been issued:

Editions uniform with the Brochures of the Society

Pages	15– 60,	plates 1– 8;	250	copies.	February	28, 1900.
"	61–106,	plates 9–14;	80	"	March	19, 1900.
"	107–114,		30	"	"	20, 1900.
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"	127–144,	plates 15–17;	130	"	"	22, 1900.
"	145–178,		100	"	"	28, 1900.
"	179–206,		230	"	April	4, 1900.
"	207–216,	plates 18–19;	130	"	"	6, 1900.
"	217–230,	plate 20;	360	"	"	7, 1900.
"	231–240,		130	"	May	7, 1900.
"	241–332,		105	"	"	10, 1900.
"	333–346,		130	"	"	21, 1900.
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"	389–416,	plate 24;	150	"	June	13, 1900.
"	417–432,	plates 25–29;	100	"	"	15, 1900.
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"	449–460,	plates 40–42;	80	"	"	22, 1900.
"	461–474,	plates 43–49;	280	"	"	30, 1900.
"	475–502,*	plate 50;	50	"	July	31, 1900.
"	503–510,		130	"	August	10, 1900.

Special Editions †

Page	2‡	30	copies.	January	31, 1900.
Pages	3– 5	130	"	"	31, 1900.
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"	10– 14	30	"	"	31, 1900.

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* In addition to the above, 100 copies were printed from the same type by Judd & Detweiler at the request of Mr Hopkins, the pagination and plate numbers being changed and the Bulletin caption at the head of the first page and line "Presented before the Society December 30, 1900," as well as cover, being omitted.

† Bearing the imprint ["From Bull. Geol. Soc. Am., Vol. 10, 1898."]

‡ Fractional pages are sometimes included.

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"	viii–ix,		130	"		"	31, 1900.

CORRECTIONS AND INSERTIONS

All contributors to volume 11 have been invited to send in corrections and insertions to be made in their compositions, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 16, line 4 from top; *for* "fourteenth" *read* sixteenth
" 16, " 5 " " ; *for* "1820" *read* 1810
" 19, " 11 " bottom; *for* "800" *read* 500
" 20, " 9 " top; *for* "north" *read* northwest
" 20, " 13 " " ; *for* "Kakuku" *read* Kahuku
" 20, " 19 " " ; *for* "north" *read* northwest
" 20, " 7 " bottom; *for* "Kaluwaa" *read* Kaliuwaa
" 20, " 3 " " ; *for* "rise" *read* size
" 21, " 1 " top; *for* "Southern" *read* Southeastern
" 21, " 4 " " ; *for* "thus" *read* then
" 21, " 16 " " ; *for* "Kalehi" *read* Kalihi
" 21, " 20 " " ; *for* "lie" *read* lies
" 21, " 4 " bottom; *for* "Panoa" *read* Pauoa
" 21, " 4 " " ; *for* "Kalihe" *read* Kalihi
" 21, " 3 " " ; *after* "Kalauao" *insert* and Waimalu
" 26, " 18 " " ; *for* "Kamahemaha" *read* Kamehameha
" 29, " 16 " top; *for* "Kalehi" *read* Kalihi
" 29, " 23 " " ; *for* "Kawaihao" *read* Kawaiahao
" 29, " 29 " " ; *for* "Kaimoki" *read* Kaimuki
" 29, " 9 " bottom; *for* "Kamehamaha" *read* Kamehameha
" 29, " 6 " " ; *for* "flowed" *read* was ejected
" 29, " 6 " " ; *for* "locks" *read* lochs
" 29, " 2 " " ; *for* "1½" *read* 2½
" 33, " 19 " top; *for* "Hanalea" *read* Hanaloa
" 42, " 18 " " ; *for* "Kaliiwaa" *read* Kaliuwaa
" 43, " 4 " bottom; *for* "east" *read* northeast
" 44, " 7 " top; *for* "4300" *read* 3300
" 344, " 13 " bottom; *for* "western" *read* Weston
" 470, plate 49, figure 1; *for* "composed of" *read* covered with

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 11, PP. 1-14 JANUARY 31, 1900

PROCEEDINGS OF THE ELEVENTH SUMMER MEETING, HELD AT COLUMBUS, OHIO, AUGUST 22, 1899

HERMAN LE ROY FAIRCHILD, *Secretary*

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SESSION OF TUESDAY, AUGUST 10

The Society was called to order at 10.15 o'clock a m, in the geological lecture-room, Orton Hall, Ohio State University. The President, Professor Benjamin K. Emerson, occupied the chair throughout the meeting. By mutual understanding between the Society and the American Association for the Advancement of Science, the Geological Section (Section E) of the Association had temporarily suspended its sessions and yielded the use of its room and time to this meeting of the Society.

ELECTION OF FELLOWS

The Secretary announced that the four candidates for fellowship had received a nearly unanimous vote of the ballots transmitted, and that they were elected, as follows:

Fellows Elected

CLEVELAND ABBE, JR., A. B., A. M., Ph. D., Westminster, Maryland. Professor of Geology, Western Maryland College.

ALFRED HULSE BROOKS, B. S., Washington, D. C. Assistant Geologist, United States Geological Survey.

WILLIAM LIBBEY, A. M., Sc. D., Princeton, New Jersey. Professor of Physical Geography, Princeton University, and Director E. M. Museum of Geology.

GEORGE BURBANK SHATTUCK, B. S., Ph. D., Baltimore, Maryland. Associate in Physiographic Geology, Johns Hopkins University.

Upon motion of J. J. Stevenson, it was voted to make H. L. Fairchild a life member, "in consideration of his long and valuable services to the Society as Secretary."

The reading of papers was declared in order. The first paper of the program was

THE GEOLOGY OF COLUMBUS AND VICINITY

BY EDWARD ORTON

Remarks were made by the President and Frank Leverett.

The second paper was entitled:

GLACIAL PHENOMENA OF CENTRAL OHIO

BY FRANK LEVERETT

[*Abstract*]

A general description was given of glacial and interglacial formations represented in central Ohio as follows: First, the Illinoian drift; second, a soil and weathered zone (Sangamon) formed on the surface of the Illinoian drift; third, a silt deposit, probably of Iowan age, which caps the weathered surface of the Illinoian drift; fourth, the Wisconsin drift, with its several moraines. The lobation of the ice-sheet in the Scioto basin and the axiradient movement shown by striæ received attention. The principal changes of drainage which have been produced by glaciation were also discussed. The paper was accompanied by a map.

In the discussion of the paper Professor W. G. Tight argued that the smooth till plains of the region might conceal very irregular surface, and that the ice-flow was not controlled by topography. Remarks were also made by the President, I. C. White, G. F. Wright, and the author.

The following paper was read by title, in the absence of the author:

GLACIAL AND MODIFIED DRIFT IN MINNEAPOLIS, MINNESOTA

BY WARREN UPHAM

The last paper of the morning session was entitled:

LATERAL EROSION AT THE MOUTH OF THE NIAGARA GORGE

BY G. FREDERICK WRIGHT

The substance of this paper is published in the Popular Science Monthly, volume lv, pages 145–154, June, 1899.

Following the presentation of this paper the Society adjourned, at 12.35 o'clock, for the noon recess.

At 1.45 o'clock p m the Society reconvened, and the three following papers were read by title:

GEOLOGY OF OAHU, HAWAIIAN ISLANDS

BY C. H. HITCHCOCK

The paper is printed in full in this volume.

RANDOM, A PRE-CAMBRIAN UPPER ALGONKIAN TERRANE

BY CHARLES D. WALCOTT

In a paper presented to this Society at its last meeting I gave a description of the Avalon series of Newfoundland.* Therein it was stated that the Signal Hill sandstone and conglomerate caps the series, the Cambrian resting unconformably on the basal terrane of the Avalon series and overlapping on the Archean. No transition beds were known between the Signal Hill terrane and the Cambrian. Subsequently Mr G. F. Matthew published an article entitled "A Paleozoic Terrane beneath the Cambrian," † in which he referred the greater portion of the red and green shales, with their interbedded limestones, on Smith sound and Trinity bay, Newfoundland, to a pre-Cambrian terrane. These shales and limestones were correlated with similar beds on Hanford brook, New Brunswick, to which he had given the name "Etcheminian."

In June, 1899, accompanied by Mr S. Ward Loper to assist in collecting fossils, I visited Smith sound, and at Smith point found the Olenellus fauna 369 feet below the summit of the Etcheminian, and one of its types, *Coleoloides typicalis*, in the basal bed of the Cambrian, on the south side of Random island. This retains the Etcheminian of Newfoundland in the Lower Cambrian, to which the strata representing it on Manuels river were referred by me in 1888. On a second visit to the Smith Sound section later in the month, Mr J. P. Howley accompanied us, and for seventeen days we worked on the Cambrian and pre-Cambrian formations about Trinity and Conception bays. The Lower Cambrian rocks of the Smith Point section are concealed at a point 441 feet beneath a thick bed of limestone, characterized by the presence of a great number of Hyolithes of various species and by Olenellus and Agraulos in its upper portion. This limestone is 369 feet beneath the conglomerate bed, which Mr Matthew places at the base of the Cambrian zone.‡ East of the interval covered by soil occurs a section 107 feet thick that evidently belongs to an older series, although it retains the same dip and strike as the reddish purple and green shales of the Lower Cambrian. The section exposed is as follows, downward:

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* Bull. Geol. Soc. Am., vol. 10, pp. 218–220.

† Annals N. Y. Acad. Sci , vol. xii, 1899, pp. 41–56.

‡ Ann. Rept. New York Acad. Sci., vol. xii, 1899, p. 46, and section fig. 3, p. 48.

	Feet
a. Sandy shales, with some bands of arenaceo-argillaceous shales; a thin layer of interformational conglomerate occurs 33 feet from the bottom, and at 17 feet from the bottom are some calcareous layers and nodules	51
b. Light gray quartzitic sandstone in three principal layers, 22, 24, and 20 inches thick, respectively	5½
c. Arenaceous shales, with thin layers of dirty gray sandstone; well marked annelid trails occur on some of the beds of sandstone and shale	51

Several hundred feet of the section along the shore are here concealed by drift, but to the eastward indurated gray sandstones and shales show in the cliffs where they are broken and distorted by dikes of basalt.

At the slate quarries east of Tilton head, on Smith sound, the basal beds of the Cambrian—green and reddish purple shales, here cleaved into slates—rest on a series of gray sandstones and shales, the dip and strike being the same, but with a thin bed of conglomerate at the base of the Cambrian. The pre-Cambrian rocks are considerably faulted and folded, but they are not the Signal Hill sandstones or conglomerates.

We next crossed to the south side of Smith sound and found the section partly concealed. Passing around Random island to Hickmans harbor, on Random sound, a section was found east of the harbor showing the Signal Hill sandstone and conglomerate, and, resting conformably on it, a series of sandstones, quartzitic sandstone, and sandy shales extending up to the base of the Cambrian. The Cambrian section extends up to the Hyolithes limestone of the Smith Point section. For the terrane between the Signal Hill and the Cambrian Mr Howley and I agreed upon the name Random.

At Hickmans Harbor point the Signal Hill conglomerate strikes north 40 degrees east; dip, 68 degrees east. At the summit of the Random terrane the strike is north 50 degrees east; dip, 70 degrees southeast. The section, as measured by Mr Howley, is as follows, downward:

CAMBRIAN.

RANDOM:	Feet
1. Reddish gray quartzitic sandstone	1½
2. Light greenish gray flaggy sandstones	3
3. Hard gray quartzitic sandstone	5½
4. Micaceous gray and greenish flaggy sandstones	68
5. Gray sandstones	16
6. Greenish and bluish gray slaty arenaceous beds, breaking up into fine shales in places	26
7. Pale pinkish quartzite in layers 1 to 3 feet	25
8. Reddish brown hard sandstone	21
9. Massive bedded white quartzite	10
10. Massive and thin bedded hard gray sandstones and shales	90
11. Dark gray flaggy sandstones	55
12. Massive bedded white quartzite	63
13. Massive bedded reddish gray quartzitic sandstone	31
	415

SIGNAL HILL CONGLOMERATE.

In number 4 of this section I found several varieties of annelid trails, including a variety about 5 millimeters broad, a slender form ½ millimeter broad, and an annulated trail 2 to 3 millimeters in width.

There is a fold in the Random rocks of the section forming a sharp syncline and anticline, and I believe that a portion of the upper part of the Random terrane is faulted out of sight. On the opposite or eastern side of the synclinal basin holding the Cambrian rocks the Random terrane appears to be much thicker, although folded and repeated several times. On the east side of Trinity bay, at Hearts Delight harbor, I measured the following section of the Random terrane without reaching down to the white quartzite which is above the Signal Hill conglomerate:

CAMBRIAN; basal conglomerate.

RANDOM TERRANE:	Feet
1. Fine silicious conglomerate, passing down into thick bedded gray and greenish gray compact, hard sandstones	45
2. Silicious and sandy shales, flaggy sandstones with thick layers of sandstone in the upper 65 feet; traces of annelid trails occur on the surface of the shaly beds	225
3. Massive bedded dark gray quartzitic sandstones with a few bands of shaly sandstone; strike at base, north 50 degrees east; dip, 75 degrees southwest	700

CONCEALED BY DRIFT.

The Random terrane is probably 1,000 feet, and possibly more, in thickness. It fills in a portion, if not all, of the gap between the Signal Hill conglomerate and the Cambrian. The erosion preceding the deposition of the Cambrian about Trinity bay appears to have been slight, as the conglomerate resting on the Random is rarely over 18 inches in thickness, and usually much less. This, however, is not a safe deduction, as great erosion may leave but slight trace, either in conglomerates or in apparent nonconformity in the dip or strike of the strata.

The Random terrane is considered to be the upper member of the Avalon series.* Animal life existed during the deposition of a portion of it, as is evidenced by clearly marked annelid trails. A collection of the form known as *Aspidella terranovica* was made from the Momable terrane of the Avalon series. It proved the supposed fossil to be a spherulitic concretion, and this removes it from among the possible pre-Cambrian forms of life.

PRE-CAMBRIAN PETROGRAPHIC PROVINCE OF THE FOX RIVER VALLEY, WISCONSIN

BY WM. H. HOBBS AND C. K. LEITH

WITH ANALYSIS BY W. W. DANIELLS

The next paper was presented by the author, as follows:

AGE AND DEVELOPMENT OF THE CINCINNATI ANTICLINE

BY AUG. F. FOERSTE

Remarks were made by H. S. Williams and J. M. Clarke.

In the absence of the author, the following paper was read by title:

LOWER DEVONIAN ASPECT OF THE LOWER HELDERBERG AND ORISKANY FORMATIONS

BY CHARLES SCHUCHERT

This paper is printed in full in this volume.

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* See Bull. Geol. Soc. Am., vol. 10, p. 219.

The next paper was entitled :

SILURIAN-DEVONIAN BOUNDARY IN NORTH AMERICA

BY HENRY S. WILLIAMS

The paper was presented only by abstract, and was discussed by J. M. Clarke and J. F. Whiteaves (a former Fellow of the Society).

The following paper was then read :

THE SECTION AT SCHOHARIE, NEW YORK

BY JOHN J. STEVENSON.

[*Abstract*]

The village of Schoharie, 35 miles southwest from Albany, is very near the mouth of Schoharie valley, an indentation of the Helderberg mountains. The section in the hills, bounding the valley at that place, extends from the Hudson to the Hamilton, and is so well exposed in detail as to afford means for comparison with sections obtained in southern Pennsylvania, as well as in Virginia, within the Appalachian region.

No trace of either Oneida or Medina appears at Schoharie, and the thin eastern representative of the Clinton rests on the Hudson. In this respect the condition differs from that in the Shawangunk mountains – the southeasterly border of the Catskill area—where the Oneida is a massive conglomerate. The contrast with the southern sections is striking. In those the Hudson passes very gradually into the red or lower Medina, as is seen well in southern Pennsylvania and still better in southwestern Virginia. *Rhyncotrema capax*, *Rafinesquina alternata*, *Plectambonites sericea*, *Ambonychia radiata*, *Avicula emacerata*, and some other forms continue into the red Medina, even to within 100 feet of the white Medina in the more southern localities.

The Niagara is represented at Schoharie by the Coralline limestone, about 6 feet thick, containing great numbers of *Favosites niagarensis*, *Stromatopora concentrica*, and a few mollusks. This dark brown limestone is succeeded by the Waterlime, in all about 40 feet thick, whose lowest portion, about 6 feet thick, is the well-known "Cement rock" of Schoharie and Ulster counties. This rock is of lighter color and very different composition. In a great part of the Appalachian region the Salina shales, often several hundred feet thick, are seen between these rocks, but in the Schoharie area the limestones are in contact and the change in conditions was so slight that the *Favosites* and other forms continued into the Waterlime, the coral occurring so abundantly in some places as to render the "Cement rock" worthless. The higher part of the Waterlime is flaggy and much of it thinly laminated, while the rock becomes more calcareous.

The passage to Helderberg is marked physically by a complete change in color, the Waterlime being light gray and the Tentaculite, the lowest division of the Helderberg, very dark blue; yet *Spirifera vanuxemi* and *Leperditia alta*, two forms characterizing the Tentaculite throughout, occur in the thicker beds of the Waterlime.

The successive divisions of the Helderberg, Tentaculite, Lower Pentamerus, Delthyris, Scutella, and Upper Pentamerus—45, 65, 95, 8, and 22 feet thick respectively—are very distinct, the color, texture, and composition of the limestones in the several divisions being characteristic. As a whole, the fauna of each division is its own, but some forms pass from the lower Pentamerus to the top, while each division contains a greater or less number of forms found in that below, showing that despite the sharp physical boundaries, there were by no means equally abrupt changes affecting animal life. Indeed, those forms which existed throughout show no differences in shape, size, or markings, such as would enable one to determine the horizon whence they came. This appears to have been the constant condition throughout the Appalachian region as far as Virginia, for the divisions are characteristic of the section.

The contact between Helderberg and Oriskany was not observed anywhere in the neighborhood of Schoharie, but at two points the concealed interval is not more than 18 inches. Apparently the change from one to the other is as abrupt as is possible. The Upper Pentamerus becomes somewhat flaggy in the upper portion, but the rock is a rather pure limestone, crinoidal and containing many cyathophylloid corals. The Oriskany, however, is a hard sandstone, slightly calcareous and very ferruginous. It is thin at Schoharie, barely 10 feet, and is seldom seen in place, its ferruginous matter causing somewhat rapid decay. The change in composition marks a physical change which sufficed to cause an almost complete change in fauna. Only *Leptæna rhomboidalis* and *Eatonia singularis* appear to have passed upward from the Helderberg. The former is excessively rare, while the latter is equally rare in the Helderberg.

Here, again, one finds a striking contrast with the southern sections. Not only is the Oriskany much thicker at the south, but there is also a transition from the Helderberg as gradual as that from the Niagara to the Waterlime at Schoharie. In southern Pennsylvania the transition bed is a silicious limestone, well shown at Hyndman, in Bedford county, and containing *Favosites helderbergiæ*, along with characteristic Oriskany forms. In Maryland the Oriskany yields fine crinoids, and crinoidal stems are common in Virginia. These are unknown in the Schoharie region. Still further south the upper beds of the Helderberg became sandy, and the admixture of Helderberg forms in the Lower Oriskany is such that the writer during his first study of the region referred the beds to the Helderberg.

The most notable differences between the sections are the gradual transition between Ordovician and Silurian and between Silurian and Devonian at the south and the equally gradual passage from Niagara to Waterlime at the north.

Remarks upon Professor Stevenson's paper were made by J. M. Clarke, H. S. Williams, I. C. White, and A. F. Foerste.

The next paper was read by title:

THE OZARKIAN AND ITS SIGNIFICANCE IN THEORETIC GEOLOGY

BY JOSEPH LE CONTE

This paper is printed in the Journal of Geology, volume vii, pages 525–544.

The following paper was entitled:

GEOLOGICAL RESULTS OF THE INDIANA COAL SURVEY

BY GEORGE H. ASHLEY

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INTRODUCTION

Under the supervision of Mr W. S. Blatchley, State Geologist of Indiana, the coal survey of the state was started in August, 1896, and completed early in 1899. Associated with the writer in the fieldwork were Messrs C. E. Siebenthal, E. M. Kindle, J. A. Price, J. T. Scovell, and Thomas Watson.

DISTRIBUTION AND CHARACTER OF THE COAL FIELDS

Geographically the Coal Measures of Indiana are part of the eastern-central, or Illinois, basin, and are found in the southwestern part of the state. A line enclosing the field would include about 9,000 square miles; but actually the Coal Measures cover only between 6,000 and 6,500 square miles, of which about one-half is underlain by workable coal.

The surface features of the coal field are largely of the flat type, common to the glacial area of the northern central states. Exposures of the country rock are rare over most of the area, and exploration is mainly by the drill. The southeastern part of the field is outside of the glacial area and ranges from very rugged along the eastern edge, where the heavy basal sandstone outcrops, to flat or rolling over most of the area to the west where shale outcrops predominate.

STRATIGRAPHY

The relations of the Coal Measures to the Lower or Eo-carboniferous are those of nonconformability. An uplift seems to have taken place toward the close of the Lower Carboniferous period, most noticeable to the north, which, through failure of original deposition or by subsequent erosion, or both, resulted in the absence of the uppermost beds of the Lower Carboniferous in that direction, and left an irregular surface, upon which the Coal Measures were laid down.

The first appearance of coal-forming conditions resulted in the laying down of one or two unimportant beds, which to the north are generally absent or, when found, appear to be confined to the hollows in the Lower Carboniferous surface. Then came the deposition of a massive sandstone along the entire eastern edge of the present coal field. This sandstone, which is occasionally gritty, is the equivalent of the Pottsville conglomerate series of Pennsylvania. It appears to have been a shore deposit, not underlying the main body of the Coal Measures, or subsequently removed, from the fact that many drillings a short distance west of its outcrop report only shale at its horizon. Between this basal sandstone and the main body of the Coal Measures is another noticeable nonconformity, as before, more marked to the north. In this case the non-coal-forming conditions persisted to the north, while several hundred feet of strata and many coal beds were being laid down in the southern and southwestern part of the field before the coal-forming conditions had reached the present northern limits of the coal area. This slow overlapping from the southwest toward the east and north was one of the most interesting discoveries made by the survey. At the extreme north coal VI is found resting unconformably on the basal sandstone, while at the south this coal outcrops 20 or 30 miles west of the sandstone, from which it is separated by over a dozen coal beds and their intervening strata.

It would be out of place here to go into the detailed history of the laying down of the main measures, though a large number of interesting features were worked out. Nonconformities occur at numerous places in the series of events, usually with erosion levels with a difference of less than 20 feet. In one case, however, the streams eroded their channels to depths of up to nearly 200 feet, cutting out the coals and other strata. These channels are abundant over the north part of the field, and are well exposed in Parke, Fountain, and Vermillion counties, due to the extensive quarrying of the sandstone with which they are filled. These channels may correspond to a nonconformity found further south between coals VI*a* and VI*b*, or to one existing between the Coal Measures and the massive Merom sandstone which overlies them.

Due to the overlap described, the thickness of the Indiana Coal Measures is variable, ranging from about 1,000 feet in the southwest to only a few hundred feet at the north.

THE COAL BEDS

In number, as high as 17 beds have been found in a single drilling, with a total thickness of over 32 feet. At least 20 coal horizons outcrop, and, counting the overlapped beds that do not outcrop, it is possible many other horizons exist. Exact information about the lower outcropping coal beds might increase the number given, as the persistence of the lower beds is assumed and not real.

In extent the coal horizons vary greatly. Some of the upper horizons are thought to have been traced the whole length of the coal field. Thus what we have called coal VII would appear to have been a practically continuous bed from the Ohio river to where its outcrop crosses the Illinois line, in Vermillion county. In the same way we have traced the horizon of coal VI continuously, though the coal is not continuous. To the south it runs out, to the north it becomes pockety, but between are two basins of several hundred or a thousand square miles each, where the coal is thick, persistent, and extremely regular in its details, clay or pyrite bands from a fraction of an inch to two inches thick persisting over the whole of the basins; so of many of the other of the upper coals, and also the accompanying beds, especially the limestones.

Going down to the horizons of coals II, III, and IV, the coals are found to occur in small basins, often of only a few acres, the coal running from 3 to 5 feet thick in the center of the basin and often running down to as many inches or nothing over the elevated divides between the basins. Yet even in such cases it is often possible to trace partings and other minor stratigraphic details of the coal from one basin to another over areas of several hundred square miles. The basin structure in most of these cases would seem to be due to the irregularities made by the erosion of the subcoal surfaces. These coals tend to be " block coals," having a remarkably perfect system of joint planes, besides usually being non-caking.

In thickness the coals range up to 10 feet. Several of the upper beds will maintain a nearly uniform thickness of from 4 to 6 feet or more over areas of several hundred square miles. The lower beds, while often reaching from 4 to 6 feet in the center of small basins, will average much below 3 feet on account of their thinness over the intervening ridges.

STRUCTURE

The major structure of the field is that of a monocline, the dip being to the south of west in the northern part and north of west in the southern part, being noticeably affected by the thickening of the strata to the south. The dip is slight, averaging about 24 feet to the mile, though running as high as 100 feet to the mile.

In its minor structure the field presents a great variety of interesting features—faults of many types, veins of clay, sandstone and coal, and local irregularities and disturbances of many kinds. Attention has already been called to some of these in the Proceedings of this Society and of the Indiana Academy of Science.

Remarks upon Doctor Ashley's paper were made by J. A. Holmes, I. C. White, J. M. Clarke, the President, and the author.

The next paper was entitled:

CAPE FEAR SECTION IN THE COASTAL PLAIN

BY J. A. HOLMES

Remarks were made by E. T. Dumble.

The next paper was read by title as follows:

OCCURRENCES OF CORUNDUM

BY J. H. PRATT

The last paper of the meeting was presented informally by the author, entitled:

TRIASSIC COAL AND COKE OF SONORA, MEXICO

BY E. T. DUMBLE

The Santa Clara coal field of Sonora, Mexico, is situated in the Yaqui river drainage, 95 miles northeast of Ortiz, near the mining town of La Barranca.

The region is mountainous. Although the elevations in this particular area are not very great, there are mountains on the north and east. Aguja, on the west, has a height of 3,950 feet, while the Carrizo, which is still higher, is on its northern border. Candeléro, another large mountain, the top of which is about 3,700 feet above sealevel, lies between Aguja and the coal field. While there are numerous peaks and high points scattered over the coal field, that portion of the area east of Candeléro is much lower than that west and is partly rolling, partly hilly. Candeléro trail, which may be called the western border of the developed field, is over 1,800 feet in height, and Tarahumari, near its center, 1,170 feet, while La Barranca in the west is 2,000 or over. From Tarahumari east the slope is considerable also, the point where the Calera empties into the Yaqui being about 700 feet above tide.

The three principal creeks are the Arellanas on the north, Calera in the center, and La Barranca in the southwest. The Arellanas and La Barranca are true canyons—long, narrow, tortuous, steep-sided, and with many falls. Both are fed by numerous springs and carry water in holes the year round. The Arellanas is much the larger of the two.

Unlike these creeks, the Calera occupies a large drainage basin, and, with its numerous tributaries, it carries off the water of several square miles. Most of its branches head on the flanks of Candeléro or in the ridges which are the continuation of that mountain to the north and south. Outside of a few springs of very moderate flow, Calera and its branches are dry, except during the rainy season.

Calera basin is the coal field proper, and was named from one of the principal affluents of the Calera, the Santa Clara, where the coal was first discovered and worked.

The rocks of the coal region are Triassic sands, clays, and igneous deposits, with a few later intrusives. A short distance south these are seen to rest upon syenites, referred by the Mexican geologists to the Archean, and on the north we have, near Los Bronces, similar syenites, and a series of interbedded quartzites and granular limestones provisionally referred to the Cambrian.

The only literature to which I have had access treating on the general geology of this region is the report by Señors Jose G. Aguilera and Ezequiel Ordoñez.* To the facts there stated I added the results of my own observations in a paper entitled "Notes on the Geology of Senora, Mexico." † Based on these, the Triassic here is separated into two divisions:

The Barranca, or clastic sediments; the Lista Blanca, or igneous rocks.

The Barranca division is composed of four members. The basal is a series of sandstones and sandy slates; the second a series of interbedded shales, slates, and sands, with occasionally a band of limestone near the top and with beds of graphite and coal. This is succeeded by a massive sandstone or quartzite carrying pyrites, which often segregate in patches and show strong colorings of iron or copper. The upper bed is a conglomerate or breccia of sandstone with a silicious matrix. This is almost always so strongly altered as to be of the nature of a quartzite, and is seemingly unconformable with the other beds.

The Lista Blanca division is a volcanic complex, consisting of a series of andesitic lavas, agglomerates, volcanic conglomerates, and tuffs, with some rhyolites toward the top. These are found resting directly upon the rocks of the Barranca division, and further north they underlie the Cretaceous deposits.

The Triassic rocks of the Santa Clara coal field belong to the second series of the Barranca division and to the Lista Blanca. The beds have a general strike northeast-southwest, and an average dip of 30 degrees southeast. The field is separated into two parts by a band of the overlaying Lista Blanca, which obscures the connection of the coal beds in the two areas.

The heavier sands are usually somewhat uniform and persistent, but at times they show considerable variability. They comprise conglomerates, grits, and medium grained sands, their massiveness depending largely on the size of the grain. They are usually gray in color, but may change to brown within a few feet. In hardness they range from friable sandstone to quartzite, but the former condition is rare. They are somewhat clayey at times, and when these clayey sandstones are metamorphosed, as they often are, it is hard to tell which is metamorphic rock and which is igneous. Occasionally the imprint of a branch or trunk of a tree is seen in them and, more rarely, a fragment of silicified wood. The slates, shales, and finer sands which make up the other beds are extremely variable, and their characters have been very well described by Aguilera.* This variability makes it extremely difficult to trace the beds with certainty, since a clay slate may pass into a sandy slate or bedded sand, or a sandy slate into a coarse massive sandstone in a comparatively short distance.

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* Contained in Bóletin del Instituto Geológico de México, nums. 4, 5, y 6. Bosquejo geológico de México.

† Trans. American Institute of Mining Engineers.

The slates are extremely rich in plant remains, which are well preserved, and many of them very beautiful. So far as I know, they have only been studied slightly as yet. Señor Aguilera gives a list of those noted by Doctor Newberry and a few others determined later, and I sent a small collection to Dr I. C. White, which was given to Professor Wm. M. Fontaine, who writes me as follows:

> "The plants that Professor White sent some time ago as coming from you and obtained in Mexico certainly come from a horizon well up in the Mesozoic. Most if not all of them seem to be new species. That and their small number make it not possible to give with certainty the exact horizon. To judge, however, from them, it appears to be the uppermost Trias or Rhetic. They impress me as being of about the age of Newberry's Abiqua copper mine plants, or those of the older Mesozoic of Virginia and North Carolina."

In addition to these plants in the shale and thin bedded slates, the more massive slates carry silicified stems and branches of shrubs, and the finer grained bedded sands trunks of trees up to more than a foot in diameter. In grain these latter resemble the elm.

None of the beds show cross-bedding to any extent.

Each prominent bed of slate and shale seems to have one or more seams of coal in it, and, although like Triassic coals in general, the deposits may be more or less lenticular, nearly all of these beds are workable somewhere along their extent in this territory.

The limestones are only occasionally present and generally near the top of the division. They are usually very argillaceous, but sometimes more calcareous.

Only a few localities have yielded fossils other than plant remains. Previous to this examination the only marine fossils known were those from San Marcial, 60 miles west of this locality, described by Meek in volume 1 of the Paleontology of California. So far I have not found here the forms described by him, but in a band of limestone I find, as imprints, a great number of other forms of marine invertebrates which have not yet been studied.

The only member of the Lista Blanca present in this immediate field is the heavy agglomerate, the basal conglomerate not appearing unless it is represented by the ferruginous quartzitic breccia placed in the Barranca division. It presents no features different from those already described.† It lies with apparent unconformity on the Barranca, but is involved with that division in its various flxeures.

The two sections given represent the general relations of the beds in each of the two areas with what seems to us the probable connection. If this be correct, they represent fully the variability of the beds in longitudinal extent as described by Señor Aguilera.

The regularity of these beds is much disturbed by intrusions of igneous rocks. This rock, which is principally trachyte, has been forced along the bedding planes of the slate or between the slate and coal for long distances. In places it may be only a foot or two in thickness, and on weathered faces so closely resemble a bed of sandy slate that its presence would be unsuspected until it thickens suddenly into a laccolite of 20, 30, or more feet, throwing the overlying beds entirely out of their regular course. The greater part of the flexures of the area are due to such laccolites.

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*Op. cit.

†Trans. American Institute of Mining Engineers.

The largest one of these laccolites is an intrusion of diorite just west of Tarahumari. It has a length from north to south of nearly half a mile and its breadth is but little less. Its thickness is more than 100 feet. It lies between the Tarahumari sand and the underlying slate, and in places has been forced between the slates as well, until it now appears to be interbedded with them.

Some of the exposures of trachytic rocks look very much like sandstones, and the resemblance is heightened by the pebbles of flint (?) and of graphite, which they often carry in considerable numbers.

While the intrusive rock probably passes from one bed of slate to another, only one or two such breaks have been observed here. It is on account of this interbedded condition that the coal beds of this area are workable, and to it is largely due the presence of workable beds of coke.

While some of the coal has a bituminous structure, analyses show that it is all anthracite. It breaks with square, even fracture, has splendent luster, black powder, and is not as hard as Pennsylvania anthracite. It contains from 4 to 8 per cent moisture and about the same percentage of ash. The volatile hydrocarbons are under 5 per cent, and the fixed carbon ranges from 76 to 85 per cent. Such tests as have been made in burning it have shown very good results; specific gravity, 1.70 to 1.75.

The coke is dark gray to grayish black in color, metallic to submetallic luster, breaks with even fracture, and shows columnar structure like oven coke. Powder black; pores smaller and coke denser than most oven coke. In places it appears lamellar, as if pressure had flattened the walls of the pores. It is a good fuel in blacksmith forge, open fire, or assay furnace, burning steadily without deflagration, and will probably be entirely satisfactory for all metallurgical uses, except such as may require a greater porosity.

The coke is simply a local condition of the coal, largely due to the presence of the igneous rock in immediate proximity of the bed.

In two of the principal openings on the coke the igneous rock practically forms the roof, and in a third instance it forms the floor of the seam. In these openings there are occasional inclusions of the igneous rock in the coke, and there are other places where it thickens and cuts the coke out almost entirely. The plastic nature of the igneous rock at the time of its intrusion is shown by the way in which the coke is mixed through it in these horses, if they may be so called, and also by the presence in the same intrusive rock, in other exposures, of fragments of graphite, which represent the passage of the plastic material along or through some coal bed.

In other beds, however, coke appears without any igneous rock near it, so far as we can find. In one seam of anthracite, which has a thickness of 4 feet, we find pockets of coke near the center, and in one coke bed we find pockets of anthracite near the base. In two or three beds we find both coke and anthracite present, but in different benches. In one case there is a clay parting 3 inches thick between the coke and underlying anthracite, but in the others no parting is found, and in one the anthracite is on top and coke below.

In one coke bed there is some tendency to concentric structure, and kidneys or eggs of coke are scattered through the more massive material.

In the vicinity of San Xavier and Los Bronces, north and east of here, some work has been done on seams of coal of Triassic age. One mine which I visited showed a bed of 8 feet of good coal with a narrow slate parting. Another had 10 feet of coal, much of which was of concentric structure, shelling out into "eggs" of greater or less hardness.

To the east of San Marcial, which is 35 miles northeast of Ortiz, some work has been done on supposed coal beds. After cleaning out some of the old works I found the beds to have a very black, bright appearance, looking like a fine face of anthracite. All efforts, however, to burn the supposed coal were fruitless. When put in the fire it would on becoming hot deflagrate violently, scattering burning sparks, which were simply very fine scales of the red-hot material, for several feet. On falling they would quickly become black again, and it was rare that we could get a fragment to show any ash at all. Whatever value it may have in other ways, as a fuel it was a flat failure. If, on further examination, this should prove worthy of a name among minerals, I would suggest the name of "garciaite," from the owner of the concession on which I first examined it. Later I found the same material in beds of the same age in the Whetstone mountains of Arizona.

The only coal found in my work around San Marcial was in the vicinity of El Salto. The only bed I saw there was fair coal, but thin. It burned all right, although the ash was considerably heavier than that in the Santa Clara coals.

The President declared the meeting adjourned.

REGISTER OF THE COLUMBUS MEETING, 1899

The following Fellows attended the sessions of the Society:

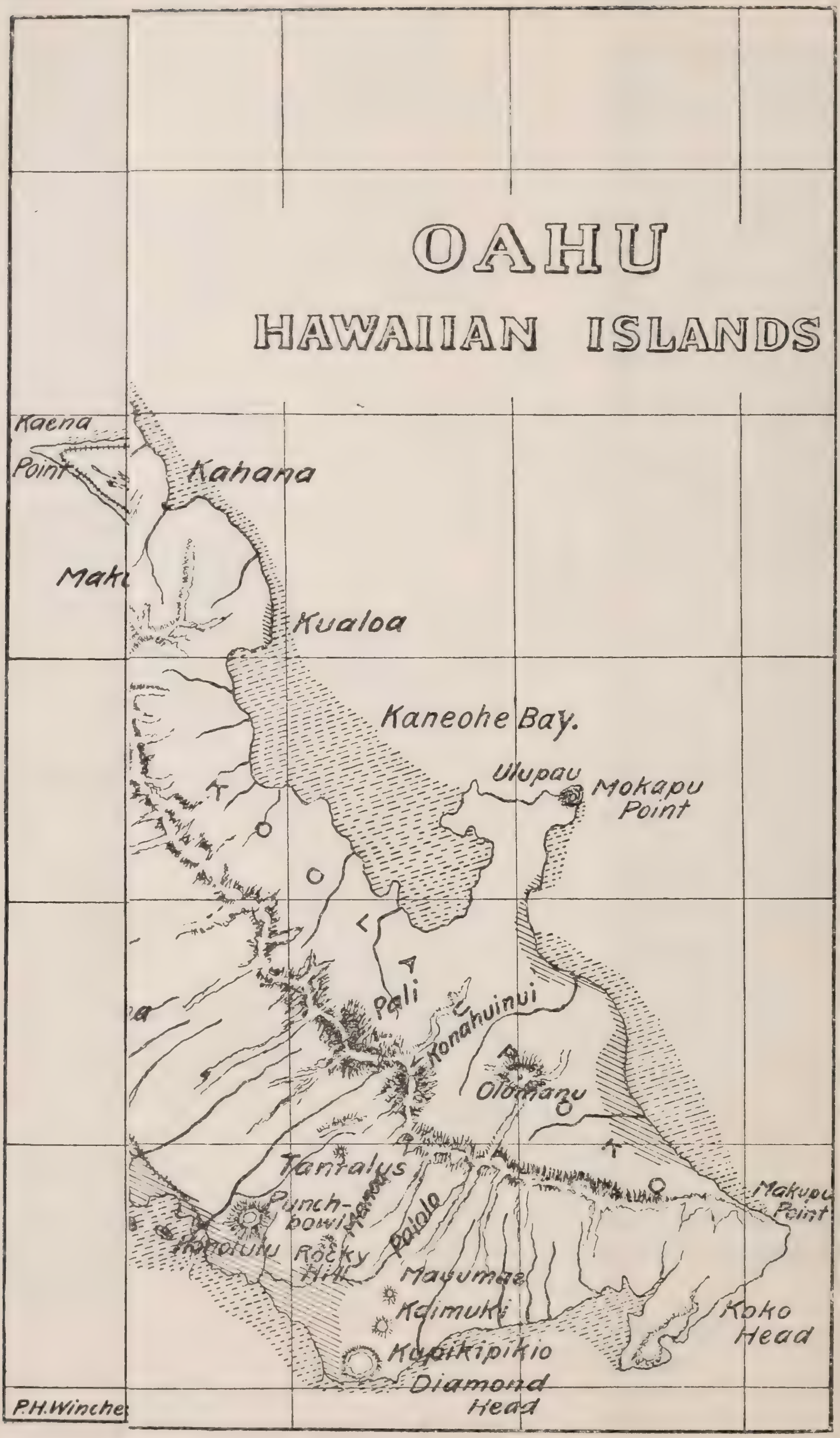
G. H. ASHLEY.
J. M. CLARKE.
E. T. DUMBLE.
B. K. EMERSON.
H. L. FAIRCHILD.
G. P. GRIMSLEY.
ARTHUR HOLLICK.
J. A. HOLMES.
C. R. KEYES.
FRANK LEVERETT.
EDWARD ORTON.
C. S. PROSSER.
F. W. SIMONDS.
J. J. STEVENSON.
F. B. TAYLOR.
W. G. TIGHT.
I. C. WHITE.
H. S. WILLIAMS.
G. F. WRIGHT.

Present at the meeting of the Society, 19.

The following Fellows arrived too late for the session of the Society, but were in attendance upon the sessions of Section E, American Association for the Advancement of Science:

E. R. BARBOUR.
H. C. HOVEY.
A. M. MILLER.
W J MCGEE.

Total attendance, 23.


OAHU
HAWAIIAN ISLANDS
Kaena Point
Kahana
Mak
Kualoa
Kaneohe Bay.
Ulupau
Mokapu Point
na
Pali
Konahuinui
Olomanu
Tantalus
Punchbowl
Manoa
Palolo
Honolulu
Rocky Hill
Mauumae
Kaimuki
Kapikipikio
Diamond Head
Koko Head
Makapu Point
P.H.Winche

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 11, PP. 15-60, PLS. 1-8 FEBRUARY 28, 1900

GEOLOGY OF OAHU

(Read before the Society August 22, 1899)

BY C. H. HITCHCOCK

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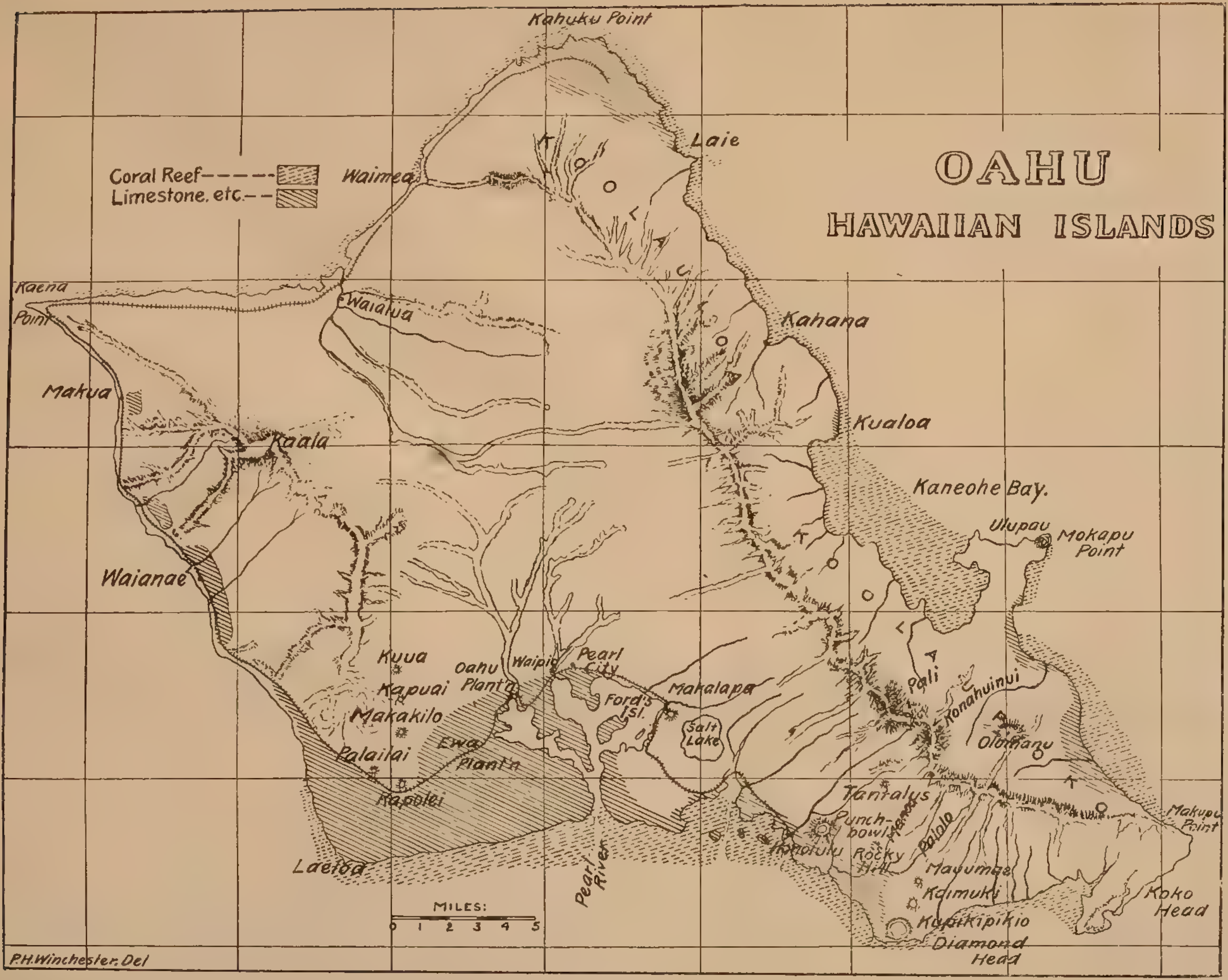
INTRODUCTION

Oahu is one of the newly annexed Hawaiian islands. It possesses the best harbor in the whole group, and is therefore the most important location for business, the chief city, Honolulu, containing 40,000 inhabitants and being situated about 2,100 miles southwesterly from San Francisco.


OAHU
HAWAIIAN ISLANDS
Coral Reef----- ▨
Limestone, etc.-- ▨
Kahuku Point
Laie
Waimea
KOOLAU
Kaena Point
Waialua
Kahana
Makua
Kaala
Kualoa
Kaneohe Bay.
Ulupau
Mokapu Point
Waianae
Kuua
Kapuai
Makakilo
Palailai
Kapolei
Laeloa
Oahu Plant'n
Waipio
Pearl City
Ewa Plant'n
Ford's Isl.
Makalapa
Salt Lake
Pearl River
Pali
Konahuinui
Olomanu
Tantalus
Punch-bowl
Manoa
Palolo
Honolulu
Rocky Hill
Mauumae
Kaimuki
Kapikipikio
Diamond Head
Koko Head
Makapuu Point
MILES:
0 1 2 3 4 5
P.H.Winchester, Del

MAP OF OAHU

The city is surrounded by an interesting group of extinct secondary volcanoes, resting on ancient basaltic flows and adjacent to a coral reef which girdles the whole island.

First discovered in the fourteenth century, the islands were rarely seen by civilized people before 1820, since which time visits of investigation have gradually become quite numerous. A multitude of allusions to volcanic or coralline formations are made in the writings of travelers, historians, and missionaries, such references being primarily to the existing active volcanoes on the island of Hawaii and sparingly to the phenomena on Oahu, all of which will be passed by in this sketch and mention made only of several important publications.

My observations were made in 1883, 1886, and during a year's residence, commencing September 1, 1898. The present sketch is complete to the extent of the author's information, but the work done has not been equally distributed over the island. The part most fully investigated was the neighborhood of Honolulu and the line of the Oahu Railway and Land Company.

LITERATURE.

The earliest publication cited is that of the United States Exploring Expedition under Captain Charles Wilkes, in 1841, and of which J. D. Dana was the geologist. His report appeared in 1849. The same author visited the island again in 1887, and adds to his early observations in papers published shortly afterward in the American Journal of Science and in "Characteristics of Volcanoes," 1890. In 1856 W. L. Green published in the Sandwich Island Monthly, for June, a paper entitled "Extinct Craters of Oahu." References to this island will be found also in part II of his book, "The Vestiges of the Molten Globe," 1887. In the Memoirs of the Boston Society of Natural History, 1868, William T. Brigham has devoted several pages to the geology of this island. Captain C. E. Dutton studied the geology of Oahu in 1882, and his account is published in the Fourth Annual Report of the United States Geological Survey, 1882–1883. Important suggestions have been presented by Professor W. D. Alexander, surveyor general of the Hawaiian islands, and by Professor A. B. Lyons, of Oahu College. Doctor Walter Maxwell has printed, under the auspices of the Sugar Planters' Association, 1898, a treatise on the "Lavas and Soils of the Hawaiian Islands," deriving many facts from Oahu.

The topography of our map is based on the excellent map of the island published by Professor W. D. Alexander in 1881, on the scale of $\frac{1}{60000}$.

Samples of the rocks, minerals, and fossils about to be mentioned, and which were collected by the author, under the direction of Professor G. P. Merrill, Curator of Geology of the National Museum, will be found in the collections of that institution.

Hawaiian Archipelago

The Hawaiian archipelago is fully 1,725 miles in length, extends from longitude 155° to 180° west, and includes many shoals and small islands usually overlooked by geographers. These islands are central in the great network of ocean highways between North America on the east and Asia, with its islands, on the west. Commencing with the one most remote, the following is the order, passing from the northwest to the southeast:

Ocean island.
Midway island.
Gambia shoal.
Pearl and Howes reef.
Lisiansky island.
Laysan island.
Maro reef.
Gardners island.
Unnamed shoal.
French Frigate shoal.
Neckers island.
Frosts shoal.
Nihoa or Bird island.
Lehua.
Niihau.
Kaula.
Kauai.
Oahu.
Molokai.
Lanai.
Maui.
Kahoolawe.
Molokini.
Hawaii.

About half of this list is what are termed *low islands*, and these lie to the northwest of the *high islands*. A limited number of soundings indicate that the archipelago rises from a plateau 18,000 feet below the surface of the sea, so that if the water were removed there would be seen a range of mountains from 18,000 to 32,000 feet high. The peaks would appear more slender than the needles of the Alps.

It is supposed that each of these eminences started from the ocean bottom as an igneous outburst. In case the lava continued to flow till a submarine mountain was built up sufficiently near the surface to allow the peaceable growth of coral polyps, there would have been superposed on the top of the mound limestones of organic origin more or less extensive, according to circumstances. After the establishment of the coral reefs, in case the islands sank gradually, as is assumed on the theory of Darwin and Dana, the limestone would have continued to develop upward, thus presenting columns of calcareous matter many thousand feet high. If the subsidence were rapid the animals would have ceased to exist as soon as they reached unfavorable conditions, and there would have remained a submerged conical peak. It is obvious that there may be every variety of development from the needles that do not reach the surface, to low-lying shoals, reefs, and to Hawaii, 14,000 feet above the sea. Inasmuch as the living volcano is found at the extreme southeast end of the group and the islands toward the northwest consist of basalt, capped by craters or show evidence of long-continued erosion, it is believed these last are older. Thus Ocean and Midway islands had their bases established long before the high islands of Oahu and Maui began to be formed, and in a general way the growth of the islands has been from the northwest to the southeast. If the Darwinian view of the long-continued subsidence of coral islands is accepted, it may be that the remote series of reefs and shoals represent the tops of high islands 6 or 8 miles above the submarine plateau. For our present purpose it is only necessary to say that the origin and development of Oahu has been intermediate between the earlier and the later islands.*

Topography

Oahu has an area of about 600 square miles, one-eleventh of that of the whole archipelago, and in form is an irregular four-sided figure, with a diameter of 46 miles in a northwesterly direction from Makapuu to Kaena point. The distance from Barbers to Kahuku point, east of north, is 30 miles. At Honolulu a northeast line is only 9 miles long from tide to tide. The extreme easterly point has the longitude of 157° 38′ east; the extreme westerly point has the longitude of 158° 17′. The extreme latitudes are 21° 15′ and 21° 43′ north. The land rises to two mountain ranges nearly parallel to each other and to the northeast and southwest shores of the island. The larger eastern one, which is 37 miles long, is called Koolau. The smaller, 21 miles long and opposite the western shore, is called Kaala. Great subaerial erosion has produced ragged precipitous faces on the seaward sides of these ranges, but the interior slopes are gentle, the height of Kokoloea, the saddle between, being 888 feet. The highest point in the Koolau range is 3,105 feet; that in the Kaala is 4,030 feet. The interior gentle slopes have been cut by canyons perhaps 400 feet deep at the outer edge of the plateau.

Several years since the author constructed a rude relief of Oahu based on approximate contours furnished by Professor Alexander. This relief has been reconstructed recently on the scale of $\frac{1}{60000}$ horizontally and twice as much vertically. It has been impossible to photograph this relief for this paper, as intended. In its place plate 1 is introduced, which will indicate the location of the localities alluded to sufficiently for our present purposes. Besides the features already mentioned, one may observe the low calcareous shelf skirting the island, mainly of coral origin. This is broadest in the Ewa district, where is situated the famous Pearl River harbor, and narrowest at the northwest and southeast points of the island. This low-lying area represents that part of the island at present capable of sustaining sugar and other agricultural industries, all of them dependent on irrigation. The more elevated regions are but slightly utilized for grazing purposes.

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* Botanical evidence furnishes additional proof of the greater antiquity of the more northwestern islands, for the flora of Hawaii is the poorest and most uniform, while that of Kauai is the richest and most individualized in species, and in general the plants on the intervening islands follow the same ratio, allowing for the greater diversity of climate afforded by elevation. W. F. Hillebrand: Flora of the Hawaiian Islands, 1888, p. xxii. Other proofs leading to the same conclusions may be derived from the study of the Achatinellidæ, as commenced by John T. Gulick and Alpheus Hyatt.

Kaala Range

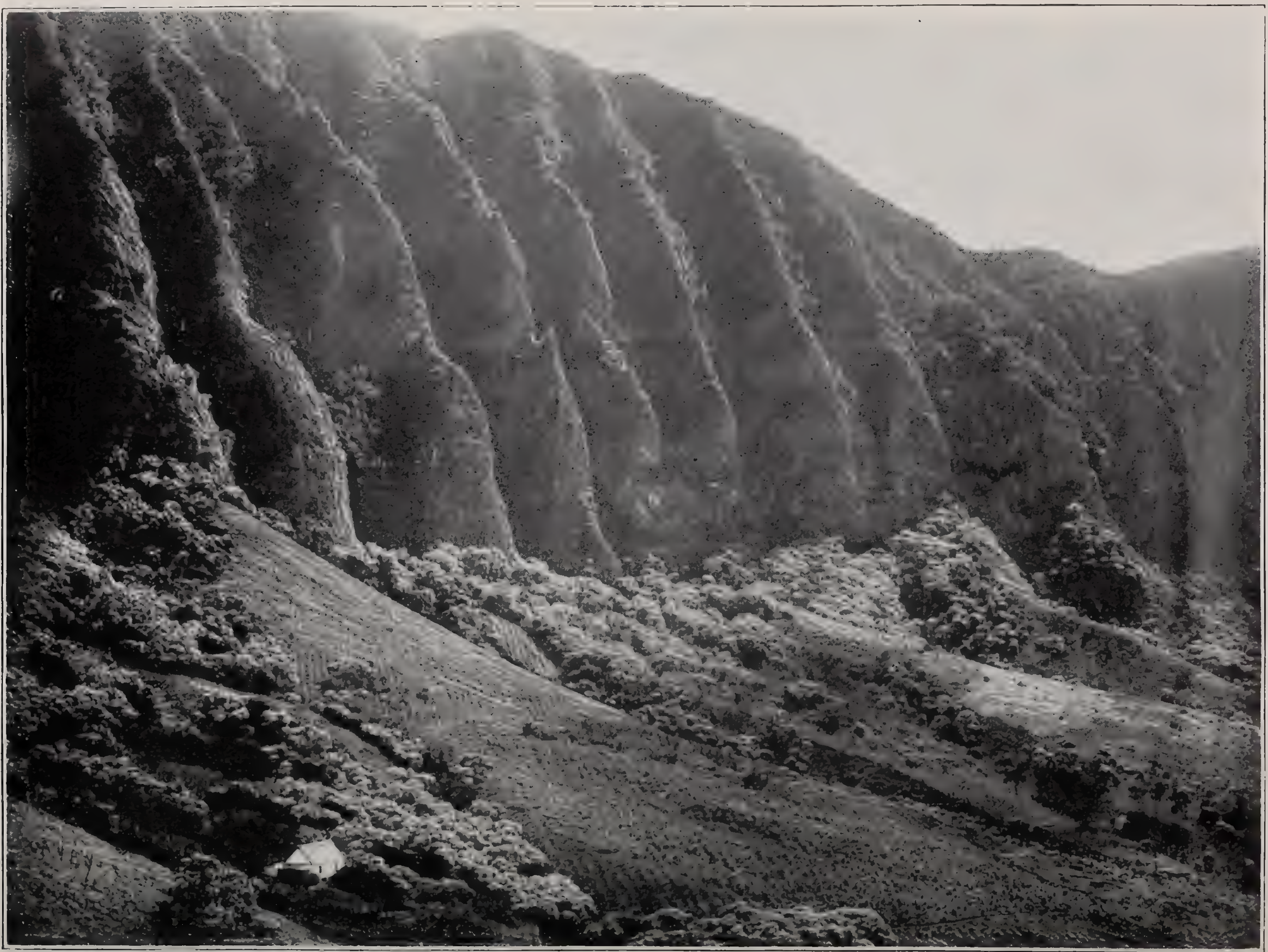
Commencing with the older volcanic mass, mention will be made in detail of its physical features, as may be gathered from the large map published in 1881. Starting at its southern extremity, the first prominent peak is Manawahua, 2,430 feet. The ground rises gradually from the south and southeast sides, but more abruptly on the west. The following represent the order and altitudes of the summits: Manawahua first, then at a distance of a mile and a half, Maunakapu, 2,740 feet; unnamed signal station, 3,110 feet; Pohakea pass, 1,870 feet; Puu Kaua, 3,105 feet; Kanehoa, 2,720 feet, with a long spur to the northeast called Maunauna, 1,772 feet; Hapapa, 2,878 feet; Kolekole pass, 1,590, in which is located the road to Waianae; Kamakalii; Kalena; Kaala, 3,686. This is the central peak in the range, the very highest point being a mile farther west, 4,030 feet, the beginning of the long northwest spur, Kamaohanui. Special altitudes for the rest of the range, 9 miles, to Kaena point are not given, but the descent is gradual, falling to about 800 feet at the bluff a short distance back from the railroad.

Five prominent ridges divide the western part of the Kaala area into six deep valleys, named successively Nanakuli, Lualualei, Waianae, Makaha, Keaau, and Makua. The largest of these measures 6 miles from the crest of the ridge to the seashore, and 3½ miles in width. Each of these valleys has been excavated by running streams in the usual manner of subaerial erosion in elevated plateaux. The valleys are fertile, fitted for the cultivation of sugar and coffee. If our attention is not too much taken by these secondary mountainous spurs, one will observe the presence of a precipitous escarpment on the seaward side of the central range, corresponding to a longer cliff or pali, as it is called in Hawaiian, on the east side of Koolau. Plate 2 illustrates the flutings or valleys of erosion made by existing streams on the side of the Kaala pali.

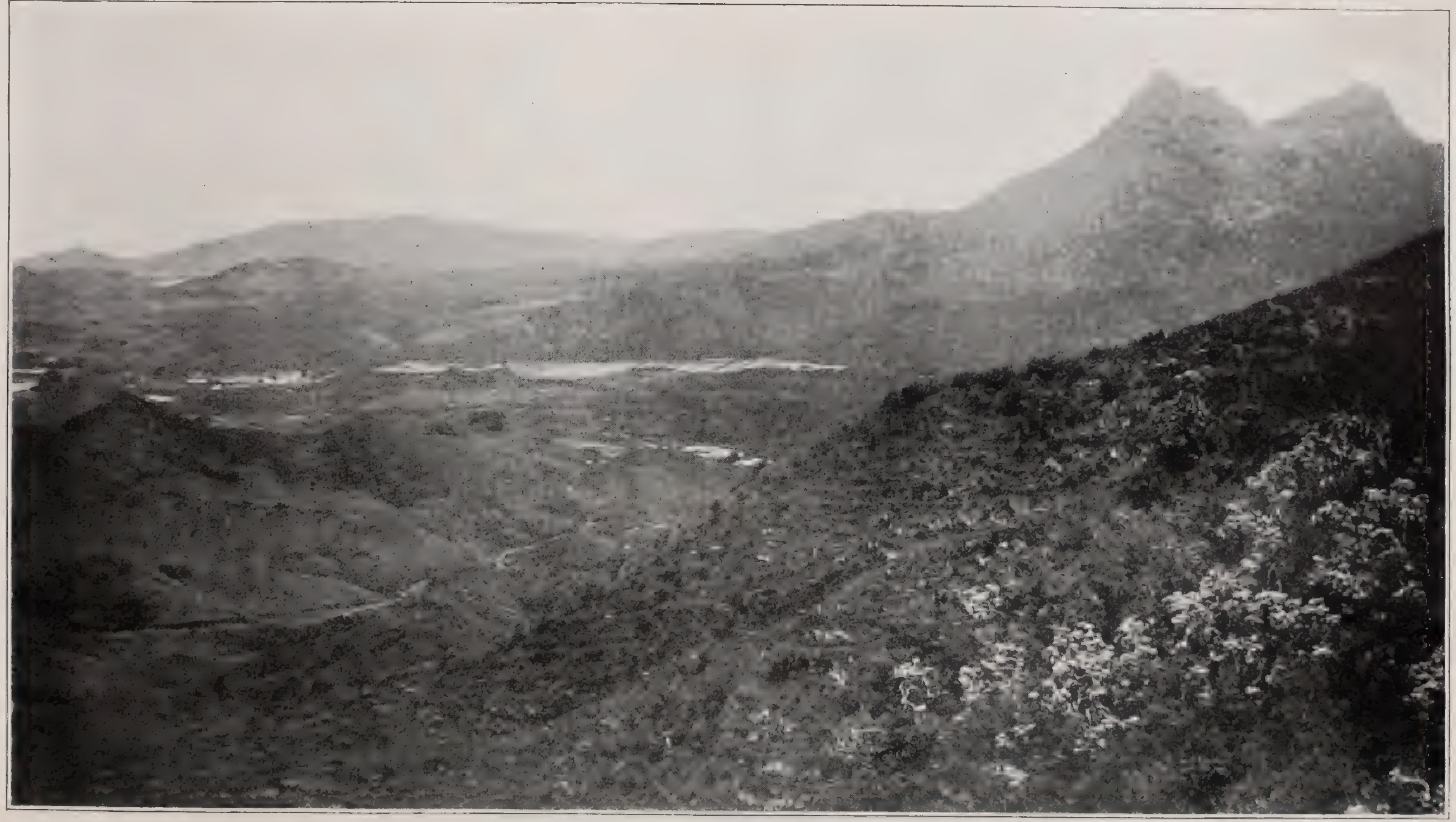
KOOLAU RANGE

The mountains in the larger eastern district are arranged naturally by their drainage into two parts, so obvious as to have received distinct Hawaiian names. The more northwesterly part is Koolauloa, about 15 miles long, reaching to the peak named Kaumakua. The drainage on the interior side is entirely to the north. The other section, called Koolaupoko, is 22 miles long, with its interior drainage directed into the Pearl Harbor system, except the southeastern part, where the streams flow directly into the sea.

The extreme northwesterly point of Koolauloa is Kakuku, where are interesting limestones to be described later. The valleys become more pronounced to the southwest, and at Waimea bay is a considerable canyon fully 400 feet deep, with many branches high up. Three or four large canyons converge and discharge in two adjacent channels at Waialua, and they drain also the northeast slopes of Kaala. The longest of the Waialua series of canyons commences on the north flank of Kaumakua and is 16 miles long. The slope may be from 3 to 5 degrees to the north from the axis of the range, making an inclined plateau which has been cut into several ravines. The greater part of this plateau has rarely been visited. It is noticeable that the western slope of Koolauloa is continuous to the very base of Kaala on the Waialua side. The same is true of the southern slope toward Ewa, with its canyons. The largest of these gorges passes through the Oahu sugar plantation. Only one altitude is given for any of the Koolauloa peaks, which is 2,360 feet at the summit, a short distance north of Kaumakua, and the descent from here to the limestone cliff at Kahuku is gradual. From Kahuku along the northeast shore the ground is low and flat to beyond the village of Laie. Off the shore are several small limestone islands. There are as many as six large valleys with steep sides between Laie and the end of the Koolauloa region. These are Kaipapau, Haaula, Kaluwaa, Punaluu, Kahana, and others. Kaluwaa presents vertical walls rising a thousand feet in pinnacles, a cascade at the end, and the "canoe," a smooth cylindrical shaft 30 or 40 feet in diameter, 300 feet high, and resembling a canoe standing on end. There is another longer channel a mile beyond, diminishing in rise upward at the top of the cliff, a thousand feet high. Both these grooves are the work of streams.



KAALA PALI AND COFFEE PLANTATION



OLOMANU FROM SOUTHEAST ANGLE IN PALI ROAD

Koolaupoko commences on the southern flank of Kaumakua, with similar high cliffs extending to the sea and making battlements, alcoves, and temples as before. Kualoa is the extreme point, from which the shoreline runs westerly, and thus takes a southeast course for about 10 miles before bending back again to make Mokapu point. Waikane is an important valley close to the beginning of Koolaupoko. For a dozen miles against Koolau bay the land is mostly low and is adjacent to the Pali; but low ridges on it show that here, at right angles to the cliff, are the same transverse valleys as at Waianae. Such names as Waiahole, Kaalaea, Kahaluu, Heeia, and Kaneohe indicate their presence.

Starting at the beginning of the elevated range, the first peaks are unnamed and unmeasured, except one at the head of Halawa valley, which is given as 2,800 feet. At the head of Moanalua valley (west side) there is a gap, the first important one thus far seen all the way from Kahuku. A second gap is at the head of Kalehi valley, not much above 1,300 feet, and the third is at the Pali, 1,207 feet, the only place crossed by a wagon road the whole length of Koolau. Lanihuli, 2,775 feet, is the mountain north, and Konahuanui, 3,105 feet, the highest peak in the whole eastern section of the island, lie to the south of the gap. Other peaks are Olympus, Lanipo, and Puuokona, before coming to the terminal cliff, 642 feet high, at Makapuu point. Two well marked ridges cross the platform on the east side. From Konahuanui a mountainous spur runs northeasterly across to Kaneohe point, more than 7 miles in length, with the following named peaks: Ulumawao, Kalahao, Kaaluala, and the crater at the end. A spur of less dimensions leaves the main range at the head of Palolo valley—Lanipo. It is worn down almost to the level of the plain near the Pali, say 300 feet, and then rises to Olomana, 1,643 feet, one of the finest needle peaks seen anywhere on the island (plate 3). To the southeast is the large triangular valley of Waimanalo.

On the south side of Koolaupoko there are nearly 20 canyons of erosion within the space of 19 miles between Makapuu point and the western section of the Honolulu sugar plantation, where the southerly sloping plateau succeeds. Those in Maunalua next Makapuu point are short and unnamed. In Niu larger ones succeed, but are without names on the map, except Wailupe, 3 miles long. Then follow Palolo, Manoa, Panoa, Nuuanu, Kalihe, two branches of Moanalua, two branches of Halawa, and Kalauao. There is an interesting series of small canyons cutting the long sloping plateau in the higher parts of the Ewa district, affording what is sometimes styled the arborescent style of drainage, and discharging into the Pearl River lagoon, and also into the ocean at Waialua (see plate 1).

GEOMORPHY

Within the two mountainous areas now outlined, the foundation rock everywhere is basalt, disposed in layers dipping quaquaversally from the central lines. Kaala was an elliptic, Koolau an elongated dome, each with its seaward sides sharply incised by canyons, and both joined together by a later formed plateau, sloping both northerly and southerly. Dana calls Oahu a "volcanic doublet," the united work of two great volcanoes which have been so greatly eroded that the proper position of their craters is now conjectural. This view is confirmed by a comparison with the island of Maui, where one of the volcanic masses has suffered but slightly from erosion and the connecting plain is nearly at the sea-level. Assuming that there were originally two volcanic domes, with layers dipping outwardly from 5 to 10 degrees, it remains to apply the principles of geomorphy to explain their present forms and their relative ages. These principles were admirably set forth by Professor Dana in his report on the origin of the valleys and ridges of the Pacific islands.* They have been applied later to Oahu, more especially by Captain C. E. Dutton.†

In the volcanic islands of the Pacific the original form of the land was that of a dome, consisting of basaltic layers of variable hardness, whether solid, vesicular, or agglomeratic, and sloping gently outward in all directions. An abundant rainfall is assured by the contact of the moist air of the trade winds with the elevated mass of land. The resultant streams wear out canyons radiating from the centers or branching from axial lines of elevation. Of the two erosive forces, disintegration and transportation, the latter is the most effective in these volcanic layers, which appear almost like the strata of sediments. In case the rainfall is unequally distributed on the flanks of the elevation, the amount of erosion will vary, as may be seen in the number, shapes, and depths of the valleys excavated.

Because the transporting power of water is greater where the slopes are steep, the valleys become larger in their upper reaches, portions of the dividing ridges disappear and amphitheaters result; outliers shape themselves out of the original plateau and at the confluence of tributaries; the spaces between the streams narrow to knife edges or may disappear; the walls, originally vertical, change to slopes through the separation of blocks by gravity, which form a talus at the bases of the cliffs. Although frost is absent, so easily are the fragments separated because of the character of the rocks that the excavation is as effective as in colder climates on the more durable ledges. In the lower reaches the streams take winding courses, and thus act laterally against the sides, widening the bases.

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* U. S. Exploring Expedition, Geology, pp. 379-392.

† Fourth Ann. Report U. S. Geological Survey.

The Koolau area is the easiest on Oahu to understand. From the details already presented it is seen to be elliptical, nearly 40 miles long, and deeply eroded along its seaward face, with many amphitheaters, outliers, and especially the long cliff opposite Kaneohe bay. There has been great excavation along the western side of Koolaupoko, but comparatively little on the interior side of Koolauloa. Judging from incomplete observations on the rainfall for the past five years, the average has been 144 inches two miles below the Pali (Luakaha), and about 20 inches near the wharves of Honolulu; but the rainfall is confessedly greater at the crest of the ridge, probably 200 inches, and it diminishes gradually all the way to the harbor. The fall along the eastern shoreline exceeds 30 inches, increasing to the summit; hence it appears the water should be most abundant along the crest of the range, but greater on the eastern than the western slope, and whatever the fall may be on the Honolulu side it came from the northeast. The erosion has been the greatest on the northeastern side, as seen in the Pali, the outliers, sometimes 2,000 feet high, the ridges running northeasterly, and the amphitheaters. It reached probably to the central axial line of elevation opposite Kaneohe bay. The cliff can not very well have been eroded by the sea, since there are irregular ridges and chains of hills at intervals of 2 or 3 miles stretching out perpendicularly from the wall and ending in promontories. Marine action would have removed these projections. The erosion seems to have been most intense at the road crossing the Pali, since there is a gap worn down to 1,207 feet from over 3,000 feet on either side, and there are two other gaps to the north not far away. Some have explained the presence of the Pali gap and the horseshoe form of the land from Mokapu point to Konahuanui and thence along the main range to the northeast branch, ending at Kualoa point, by assuming a break or fault at the Pali gap or the existence of an enormous crater in the part of the circular ridge just delineated. The best argument in reply to both these volcanic theories is that the topography is in better agreement with what is known elsewhere to be the results of subaerial erosion. If there were one transverse fault, there must have been three, quite close together, for the first cataclysmic theory; and the theory of the large crater assumes that certain cinder cones and scoria were intimately connected with it, which seems to have been formed in a different way and in later periods.

On the leeward side of Koolaupoko notice has already been taken of about 20 canyons in as many miles. This is where the island is narrow and the rainfall is ample for the work accomplished, though the erosion has been less than on the windward side. Relatively little work has been done farther to the northwest, all the way to Waialua and Waimea. A part of this lack of erosion may be due to a smaller rainfall, stated to have found its maximum at the Pali gap. Certainly erosion has not proceeded far enough to excavate gorges high up, nor amphitheaters. The shallow canyons on the north shore and in Ewa are certainly suggestive of a very scant or recent action.* From any hill like Punchbowl or Leilono one can see a fine long stretch of this sloping plateau, which has been utilized for the growth of sugar cane.

The Kaala dome presents phenomena of erosion very similar to those of Koolau, but the great excavations have been effected on the west side, as evidenced by the valleys of Waianae, Makaha, etcetera, while the gradual slopes of the Koolau area impinge closely on the latter, and the drainage has been forced westerly. The work accomplished has been on the southwesterly side, whereas the trade winds have blown from the northeast for nine months of the year. Shall we say either that there must have been a greater fall on Kaala in ancient times, or that the present precipitation of moisture has been adequate for the results? Such views are common, and had been expressed in the first draft of this paper. It was recalled that the wind blew from the west on our own visits to that region; also that the erosion is effected more by sudden downpours than by ordinary rains, and that consequently the existing fall is sufficiently adequate. Opposed to this is the general aridity of the Waianae region as contrasted with the abundant verdure of Kaneohe bay. Reflection has suggested a better view. The Kaala dome existed before the Koolau mountains were raised very much above sealevel. The ocean came perhaps half way across the island, and the trade winds impinged against the basaltic piles, dropping moisture, which excavated the eastern side very completely, and then carved out the valleys on the leeward side, together with the Waianae wind gap. Two or more lengthy ridges have been mentioned as protruding easterly from Kaala. In later times Koolau came up from the depths and poured over the skeleton ridges on the east side of Kaala, so as to conceal them from view, and there is the plateau with gentle dip covering the interior of the island, the drainage forced to the base of Kaala from Koolau, and the later excavation of comparatively small canyons. This view does not force us to believe in the existence of climatic conditions different from those now prevailing, and it enables us to interpret what has happened from the varied topography.*

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*On both sides of Ewa the slopes are protected from heavy rainfall by the opposite ridges; but from Salt lake to Koko the Koolau mountain is exposed to the kona or southwest storms; hence the deeper canyons. Note by S. E. Bishop.

This view is confirmed by observing a more decided contrast on the adjacent double island of Maui. The smaller, older mass of Eeka, in West Maui, has suffered much greater erosion than Kaala, and has also its wind gap, while the gigantic Haleakala, which has poured out sheets of lava almost in historic times, presents only the modern type of small canyon erosion on its windward side, and the leeward side has not been affected. The contrast between the two parts of Maui is more marked than upon Oahu, but it is the same in kind and may illustrate the similar sequence of Kaala and Koolau.

Artesian Wells

About 20 years ago it was discovered that good water could be obtained by sinking artesian wells near the seashore. By 1884 no less than 96 had been bored, nearly all of which yielded water. A list of them in Thrum's Annual for 1884 shows 53 in Honolulu district, 19 in Ewa, 21 in Waialua, and 3 in Koolau, at the northeast end of the island. Since that time the number has doubled. I have the records of many of these wells, and will state what general conclusions may be drawn from them.

1. The water-bearing stratum comes from a vesicular basalt situated deep down the Kaala and Koolau series. The rains soak through the permeable layers till this particular rock is reached.

2. Flowing water shows itself only in a narrow belt of territory adjacent to the seashore. At Honolulu the highest altitude reached by the flow is 42 feet. In the Ewa district the limit is 32 feet; in Waialua 21 feet, and near Kahuku 26 feet. Now that the number of wells has greatly increased, this limit is lowered to the amount of 7 feet at Punahou, but the exact figures for other localities have not been ascertained. Professor C. J. Lyons says the artesian well level about Honolulu fell during the month of July, 1899, from 35.1 feet to 34.6 feet, because of the semi-annual flooding of the rice fields. Wells sunk above the limit of flowing

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*After writing the above, I find a somewhat similar statement of some of the facts by Professor Dana. He says, "That the volcano of East Oahu was in full action long after the extinction of the western cone is shown" [in 1840 and 1887] "by the encroachment of the eastern lava streams over its base and the burial in part of the valleys." "The depth of burial by the East Oahu lavas was probably some hundreds of feet." A figure shows the steep east wall of Kaala just behind the newly encroaching lavas. Characteristics of Volcanoes, p. 301.

water, as at Makiki reservoir, contain water which rises 40 feet above the sealevel within the bore-hole and must be pumped to be utilized.

3. The depths at which the water has been reached average about 500 feet, but are very variable, and I have not yet discovered whether there is any law determining the position of this level. The deepest well, that of James Campbell, at the seashore near Diamond head, was sunk 1,500 feet, but as no fresh water appeared, the boring was abandoned. The water rose about a foot above the normal level in shallow wells, and was briny as sea water itself. A similar case is mentioned at Waialua, where very salt water only was found at a greater distance from the ocean. Quite near to it, however, another boring furnished fresh water. Not very far away from the James Campbell well, at Waikiki, another boring proved successful at the depth of 820 feet. Within half a mile easterly from the High School water was found at 420, 616, and 509 feet; toward the sea, southerly, a less distance, at 762 feet, and a couple of blocks westerly, 762 feet. About Punahou, 8 wells range from 213 to 370 feet. In the Ewa district the range is from 273 to 692 feet; at Waialua from 200 to 590; in Koolau from 300 to 400 feet. A well at Waikiki, tested by W. E. Rowell, superintendent of public works, proved to discharge 18 gallons to the second. At the largest pumping station on the Oahu plantation 12 wells, each one foot in diameter, have been bored within the limits of a building perhaps 60 feet square, and large engines are constantly pumping water from them with no sign of exhaustion.

4. Copious springs of fresh water are found at various places around the island within the same artesian zone of elevation, as the Kamahemaha spring, beyond Punahou, near the railway station Honolulu, near the railroad in Waialua, etcetera; hence it would appear that the fresh water is disposed to discharge itself near the seashore wherever possible; also that it is the pressure of the sea water that causes the artesian liquid to flow up to the level of 42 feet; or perhaps it would be better to say that the ocean is a species of dam, causing the surplus water to discharge wherever any outlet can be found, up to the 42-foot level. Professor J. Le Conte says that fresh water rises in the midst of the ocean off the Hawaiian islands.* Such streams must have been akin to those that make the springs near the seashore. In this connection it is interesting to ascertain whether the brine of the sea affects the quality of the artesian water by its contact. As this is an important practical question, various analyses have been made, both at the sugar plantations and at the reservoirs containing potable water for domestic uses. It has been found that there is a certain amount of chlorine in the water of those wells nearest the sea, but that it diminishes inland. At Ewa plantation

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* Elements of Geology, p. 74.

the water at the lowest pumping station (number 1) is brackish to the taste, but shows no deterioration at the middle (number 2) and upper (number 3) stations, a half a mile and a mile farther inland. Mr J. B. Atherton, president of the Ewa Sugar Company, has kindly furnished me with a few analyses of the water from those and of two other wells as near to the sea as number 1, which are given herewith.

Analyses of Water from Ewa Plantation

	Pump number 1.	Pump number 2.	Pump number 3.	Pump number 5.	Mill.
	1891, May 5.	1891, July 25.	1897, August —.	1897, December 7.	1897, December 7.
	Grains per gallon.	Grains per gallon.	Grains per gallon.	Grains per gallon.	Grains per gallon.
Total solids	41.45	20.11	35.741	42.4	69.6
Silica (SiO_2)	4.49	4.89	4.351	5.0	4.9
Iron and alumina { Fe_2O_3 Al_2O_3 }			0.409	0.3	0.3
Lime (CaO)	5.92	1.51	2.88	3.0	3.3
Magnesia (MgO)	2.41	1.96	3.83	3.6	3.5
Soda (Na_2O)	10.28	3.87	8.71	5.7	20.0
Potash (K_2O)				0.6	2.0
Chlorine (Cl_2)	17.61	8.18	11.97	12.4	28.7
Sulphuric acid (SO_3)	1.89	1.20	2.44	1.9	2.5
Phosphoric acid (P_2O_5)				0.07	0.06

The composition of the fresh waters of the islands has been very carefully determined by Dr Walter Maxwell* as follows:

	Per cent.
Silica	.0023
Iron and alumina	.0005
Lime	.0013
Magnesia	.0013
Potash	.0005
Soda	.0033
Chlorine	.0040
Sulphuric acid	.0011
Phosphoric acid	.0001

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* Lavas and Soils, etcetera, p. 170.

He states also that he has ascertained the fact of the presence of marine salts in the artesian waters nearest the seashore. In addition, I may say that I have ascertained from the engineer at the pumping station on Beretania avenue that the amount of scale in the boilers left by the evaporation of artesian water is greater than what he has seen coming from spring water in other parts of the world, but the amount of the deposit is not large.

5. Most of the wells pass through considerable limestone, which is usually supposed to be an ancient coral reef. Thus in the deep James Campbell well "hard coral rock, like marble," was encountered between 320 and 825 feet—that is, of a thickness of 505 feet. In King's well number 2, less than half a mile from Campbell's, there is nearly as much of the limestone below 150 feet, but mixed with clay for 100 feet of the way. No other wells show so much limestone. In Goo Kim's wells, a mile inland, there were 26 feet of limestone above 150 feet, and 194 feet above the level of 430 feet, including two intercalations of 20 feet of clay. In the three adjacent wells of G. N. Wilcox, Mrs Ward, and the ice works (Kewalo), the limestone extends downward to 400 feet. At Thomas square, at the pumping station, and the Queen's hospital the limestone occupies 200 feet in thickness at the surface. Other wells show a less amount. At the Makiki reservoir no limestone was encountered in two wells, 900 and 970 feet deep respectively, and the water rises to 40 feet above sealevel. In Jaeger's well, Makiki, a log of cocoanut wood was found at a depth of 245 feet beneath 150 feet of limestone. It would seem proved that this limestone does not extend beneath the Koolau basalt, and that it spreads over the underground surface to the depth of 700 or 800 feet in Honolulu (1178 for "broken corals") and to a similar depth in Ewa. I have been careful thus far not to use the word coral reef, because the material has probably been blown or drifted from its place of origin, and thus does not necessarily imply a subsidence of the land for 800 feet.

6. This limestone is overlain by lava in quite a number of wells, as at G. N. Wilcox; Marquez, at the mouth of Manoa valley; King's well number 2, at Waikiki; Pua, near Moiliili; Wong Kim, at Waikiki; three at Kalihi, government building (old palace yard); T. R. Foster, and others. I have observed basalt over the existing reef at several localities to be mentioned later.

7. Diamond head is of more recent origin than the limestone, because 270 feet of the peculiar tufa of this crater overlies the limestone in the James Campbell well. At the Queen's hospital the record is, first, black volcanic ash, 10 feet; "coral," 13 feet; tufa of Punchbowl, 47 feet; "coral,"

30 feet, etcetera; hence it would appear that the Diamond Head and Punchbowl tufas were ejected through this modern limestone.

CORAL REEF

Oahu is mostly encircled by a fringing coral reef, whose limits are exhibited on plate 1. At low tide one can walk a long distance on this reef in various directions, off the city of Honolulu, near Koko head, and in Kaneohe bay. The polyps living on and enlarging the reef are of the genera Porites, Pocillopora, Astrea, Meandria and Fungia, together with Millepora, echinoderms, mollusks, serpulæ, gorgoniæ, nullipores, with seaweeds, etcetera. The life is much better developed at Kaneohe bay than at Honolulu, because the trade winds impinge directly against the shore, bringing food in great abundance to the animals, while the harbor is on the lee side of the islands and subsistence is less easily obtained. Where the fresh-water streams of Nuuanu and Kalehi valleys and Pearl river enter the sea, channels are produced, because the animals can not flourish in fresh water. The Nuuanu channel is utilized for shipping, and the Pearl River outlet bids fair to form the entrance to the finest harbor in the Pacific ocean when the bar at the mouth has been removed.

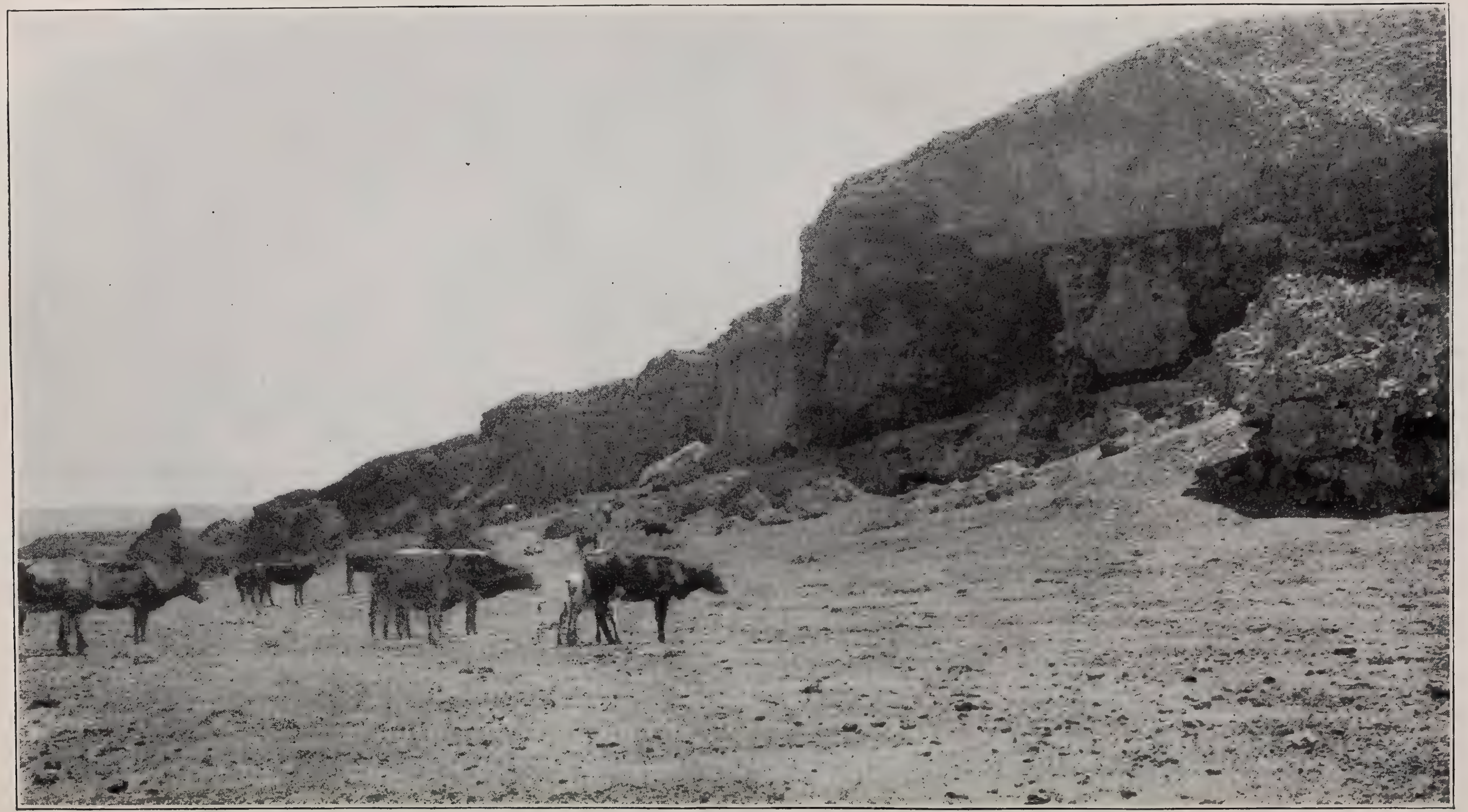
The loose character of the ordinary reef rock is shown in the large blocks used for stone walls and buildings. A better quality is exhibited in the walls of the Kawaihao church, and the very best is a compact variety made by the washing of limestone fragments into fissures and cavities, which have been cemented by its own substance in solution. The sea water has worn the reef into very irregular shapes, not easy to walk on.

The plain of Honolulu rests on coral limestone, beginning easterly near Moiliilii church and Paakea, and it has been covered by the basaltic flow of Kaimoki. It crops out in many places within the settled districts, as on the banks of the Nuuanu river near Palama chapel and seaward from the terminus of the tram railroad at Kapalama. A very large excavation in it shows an abundance of corals and shells. Boulders of basalt strew the surface of the unexcavated portion, and it may extend beneath the Kamehamaha schools and Bishop museum, being fully 20 feet above the sea. The original floor of the crater of Aliapakai consists of coral, and it both overlies and is intercalated in the tufa that flowed from Makalapa, exposed along the railway in the southeast locks and the islands opposite. Most of the islands and points about Pearl river consist of this material, as at Fords island, Pearl City peninsula, Laulaunui, etcetera. About Ewa plantation the limestone area is 9 miles long and 1½ miles wide. It skirts the shore and railroad the whole length of the southwest shore of Oahu. At an abandoned quarry 3 miles north of Barbers Point (Laeloa) light-house the best quality of the sandstone is well developed, and was used in the erection of the Saint Andrews English cathedral. Agassiz speaks of this material as a "massive coral pavement sandstone."

There are three varieties of material at this locality: At the base, the underlying rough reef loosely put together, a sandy limestone, and above all, the compact pavement sandstone, capable of affording a good polish. The total height is about 16 feet. This compact rock has been utilized also in the manufacture of quicklime. It is a good place in which to observe the manufacture of the sandstones, for shells and corals are strewn over the beach in all stages from the live animal to worn cobbles, pebbles, sand, and firm rock. Crystals of calcite are frequently seen in the consolidated rock.

Proceeding northerly, Professor Alexander reports a ledge of coral 79 feet above the sea, at Kahe, and 730 feet distant from the water, south of Puu o Hulu, he mentions another ledge 56 feet above the sea and a quarter of a mile inland; also on the south side of Lualualei, 20 feet high. At the south end of the ridge called Mailiilii, the limestone reaches the height of 81 feet; at other localities on this coast I have observed limited areas of the same substance more or less elevated.

The plain of Waialua shows many outcrops of the reef; Kahuku, the extreme northern point of Oahu, is the most interesting locality. The Koolau highlands ends in a bluff nearly 2 miles back from the extreme point, rising to a hundred feet or more from a flat plain. This bluff consists of coral rock up to 60 feet, capped by blown calcareous sand now firmly consolidated, which may extend inland to a height of 250 feet. Plate 4 shows both these varieties of limestone: First, the reef up to 60 feet, at the line just above the principal cave opening; second, the consolidated sandstone higher up. Large blocks of the latter material have fallen from the cliff on all sides, and similar masses in the edge of the ocean adjacent are large enough to constitute islands, delineated on maps of a large scale. At various localities in the neighborhood I found corals and shells in the underlying limestone, but nothing in the sandstone above, save perhaps a shell brought by a hermit-crab. Professor Dana has given a very effective figure on page 302 of his "Characteristics of Volcanoes," illustrating this plane between the two limestones. Nowhere on the windward side of the island do the winds blow more vigorously than here, and hence the explanation of the great altitude attained by this blown consolidated sand. For 5 miles southeasterly, to even beyond Laie, the coral plain is quite extensive. Knobs of the consolidated sand with inclined strata rise to the height of 35 feet, and sometimes suggest an assemblage of kames. Several other localities of coral mate-



CORAL BLUFF AT KAHUKU

rial might be mentioned on the windward coast between Kahuku and Kaneohe, of which the most important is at Kahana. There is also a broad area of it at Waimanalo.

East of Diamond head and Kaimuki the consolidated sand is very extensive, attaining the altitude of 100 feet and more. This has heretofore been called an elevated coral reef; but it exhibits abundantly inclined lamination of the sandy layers. The real reef appears at Niu and at the fish pond at Maunakea.

As of minor interest, it may be mentioned that the unconsolidated coral sands constitute a hill fully 40 feet high near Makua, adjacent to the railroad, which give forth the peculiar sounds meriting the title of "barking sands." Both these and the exposures at Kaena point abound in long tubular concretions standing vertically, which when unsupported are accumulated like roots of trees. At the latter locality I found skeletons of Hawaiians uncovered by the wind, and bones of a large sea bird.

On the seashore, at several places, I found coniferous logs, with stumpy roots and branches, which drifted from the Oregon coast. Some of them were enveloped by soft barnacles. They indicate to us the possibility of the transportation of hardy terrestrial mollusca and the seeds of plants from remote regions. After the stranding of the logs the animals will leave them, and finding the conditions of existence favorable, will multiply and assume new characters in accordance with the principles of evolution. Such I understand to have been the origin of the diverse Achatinellidæ. Ever since the country has been settled these logs have been noticed, some of them of immense size.*

Pearl River Series

The coral reefs and limestones are intimately associated with sedimentary deposits and volcanic flows, partly ashes, often disintegrated. The whole assemblage is really a terrane about 1,000 feet in thickness. It is best developed about the Pearl River locks, and hence for convenience it may be termed the Pearl River series. Probably this series of deposits began in the Pliocene, and the older layers may be a base on which the volcanic ejections commenced to accumulate. Some authors think that extensive Tertiary deposits are necessary for the starting of volcanic activity in every country. If so, parts of the Pearl River beds will be found beneath Koolau and Kaala. This series is evidently to be compared with the thick limestone deposits in the Fiji islands, supposed by Doctor Alexander Agassiz to underlie the living coral reef of that archipelago and to have been elevated as much as 800 feet, and Doctor W. H. Dall presents tentatively the opinion that the fossil shells of these beds may be of Pliocene age.* I have had the pleasure of examining these limestones at Suva, Fiji, for as much as 500 feet of thickness, and am satisfied that the Hawaiian terrane may be correlated with them, though not so much elevated. Doctor Dall has recently examined the most characteristic localities about to be mentioned, and has kindly stated his views as to the age of the strata in his notes appended to this paper.

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* For a full description of the coral reefs of the Hawaiian islands, see A. Agassiz, Bulletin Mus. Comp. Zoology, vol. xvii, no. 3, 1889.

Owing to thorough disintegration, it is not easy always to discriminate between a decayed lava and an earthy sediment, especially as lavas or ashes are constantly intercalated with strata. I will speak of these deposits at several localities where they may be easily examined. One of the most important may be seen in a railway cutting a short distance east of the Waipio station, west of Pearl city, on the line of the Oahu Railway and Land Company. The deposits seem to be arranged as follows from above downward:

I. Ten feet of a reddish-yellowish earth, constituting the soil.
H. Six feet of gray slaty colored earth.
G. Two to 8 feet of limestone and marl.
F. One to 2 feet of pure kaolin, best seen in the fields east.
E. Three or 4 feet of bluish and other clays.
D. Bed of oyster shells, 1 to 2 feet thick.
C. Two and a half feet of ferruginous clay containing large nodular masses of black hard clay, apparently carbonaceous.
B. Six inches of greenish clay, with blue stains of what may be iron phosphate or manganese oxide.
A. Four or 5 feet thickness of clays, extending downward to the track of the railroad and to an unknown depth.

The uppermost of these layers may be followed along a sort of terrace northerly to Oahu mill, and the gray layer shows itself wherever a cut has been made deep enough to reach it. West of Oahu mill the kaolin is recognized along the road leading west for one-fourth of a mile, and also along the branch railroad half a mile out from Waipahu station. It comes in contact with basalt, probably unconformably, along the railroad and overlies a pebbly rubble whose constituents are so decayed that they will crumble under the pressure of the hand, and is over an agglomerate that may be connected with the basalt. The Waipio cut is repeated on a larger scale in a railroad cut easterly from the Ewa upper pump (October 14, 1898). The basal greensand is thicker, as is the kaolin, and the greater part of the upper material is a red earth, the exposure here being about 40 feet thick. It is likely there is a direct connection between the kaolin of the Waipio cut, the neighborhood of Oahu mill, and the railroad cut near the Ewa upper pump. At this locality the lava is in part vesicular, in sheets, very much decayed. Following the railroad to the middle pump, this lava is covered by a thick layer of cobbles and pebbles mixed, which continues almost to the lower pump along the ravine, underlaid by what seems to be very soft lava. This is on the edge of the Ewa Plantation plateau, which may be 60 feet above the sea, and said to rise to 160 feet where crossed by the government road.

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* Amer. Jour. Sci., August, 1898, p. 165.

Crossing over the fish pond from Waipio to John Ii's tomb, the rock is calcareous with fossil shells, either *D* or *G* of the section. East of the Waipio cut along the railroad we see first the upper red earth, and then beneath the same pebbly layer seen in the Ewa ravine. Going west from Waipio, at Hoaeae station is a cut in the red earth, cut by two vertical dikes of sand. About a mile west of Hoaeae there are excavations showing a thick earth covered by the pebbly deposit unconformably, and both by loam. A dike of sand extends downward from the pebbles into the earth.

South from the Waipio cut on the peninsula a calcareous sandstone is found at the south edge of Eo pond. Near Hanalea pond is a large quantity of marl, and possibly kaolin, *G* and perhaps *F* of the section. At the southwest corner of Hanalea pond is an abundance of limestone with fossil shells and corals. East of this pond the rock appears more like the ordinary reef.

Near Ewa church, northeast from Waipio, the section is more of a volcanic character. At the base is an unaltered basalt of the agglomerate kind, consisting of large stones or spherules, cemented by a reddish material, which is apparently the result of decomposition of the original rock, for there is every grade of transition, from the compact unaltered rock to that containing spherules and that which is entirely a soft earth. There are bunches or areas of the hard basalt in the midst of the softer varieties, and this difference in what seems to be one layer is analogous to variations in the character of the rock at the living volcano. The gases inducing decay are abundant in certain spots and absent from others. The boulders weather concentrically, and are of the same kind with what are often strewed over fields, like the ice-carried stones of glaciated regions. Above this are a few layers of what is very near hematite, a known decomposition product of lava. This is covered by earth, and that by a mixture of sand, earth, and rubble. The hill or plateau is capped by red and yellow earths, each a fathom or more in thickness. The total thickness must be 60 or 70 feet.

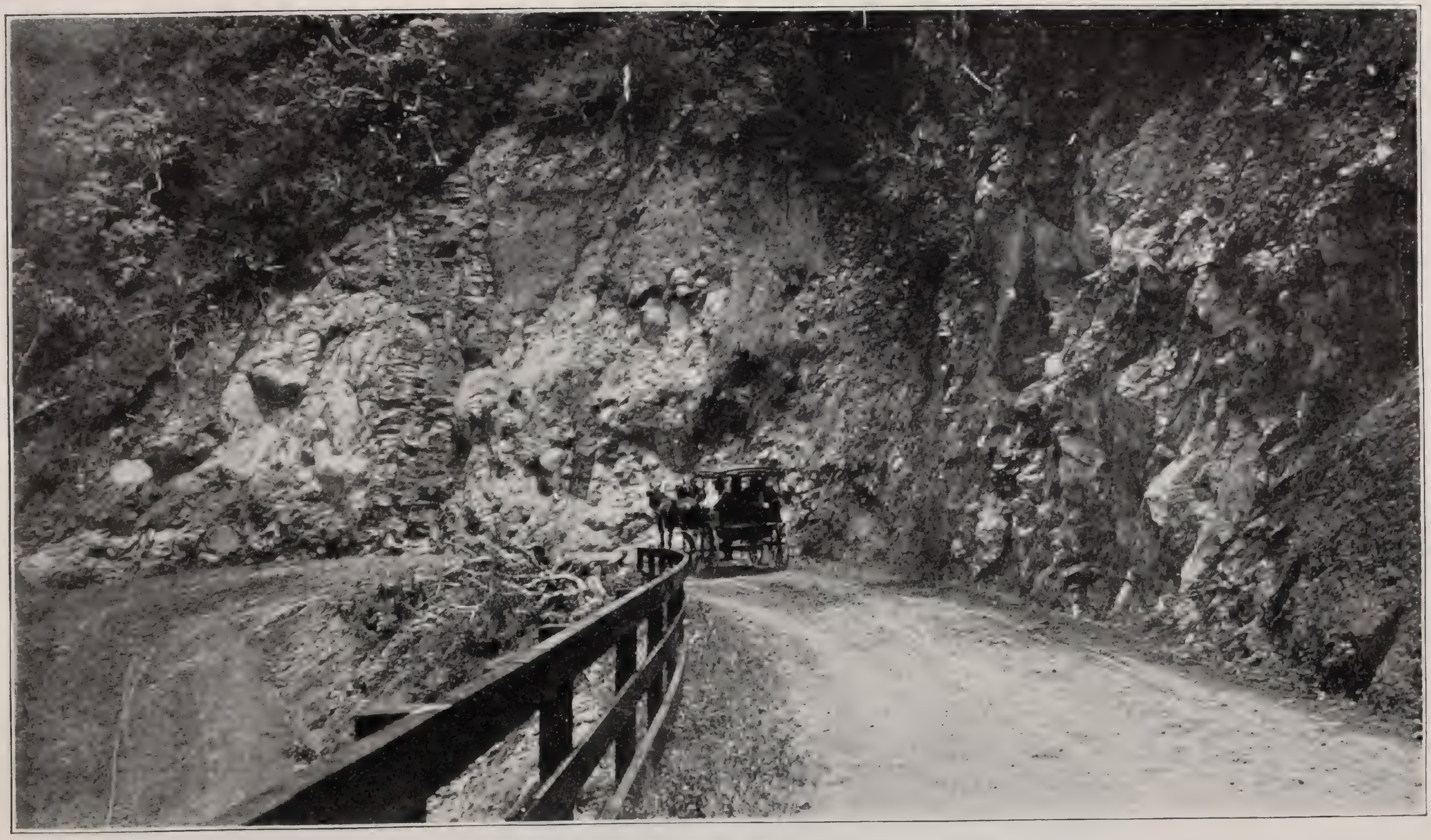
From the Laeloa craters across to the eastern part of the Honolulu sugar plantation or to Halawa station on the railroad the surface is largely composed of the upper earths of the section, constituting the substratum of the soils found to be very suitable for the growth of the sugar cane. At a deep railway cut one-fourth of a mile west from Aiea station is a thick mass of earth, capped by 8 or 10 feet of coarse pebbles and cobbles, cemented together so as to constitute a conglomerate, all of whose constituents are rounded. These stones increase in size in passing across a stream near the business center of the Honolulu plantation. Starting at the sealevel, at Aiea station, the following is an approximate section up to the top of the plateau, about 60 feet: At the base, 4 feet of greenish clay and pebbly earth; 1 foot fine volcanic ash, consolidated; 4 feet of tuff; 1 foot of clayey ash; pebbles and clay, 4 feet; tuff and ash, 8 feet. Back of this cliff is an indefinite amount of drab and gray earths, with layers of silica. On the summit of the plateau I found marine shells and corals, some of which are like those used for food by the natives, so that this is not a clear case of a submarine deposit, though it probably is, as some of the organisms are not edible. On the branch railroad leading from Halawa up to the sugar plantation is an interesting cut through earth capped by a fine grained volcanic ash, 3 feet thick, well filled with leaves of dicotyledonous plants. The ash was apparently blown from Makalapa and consolidated. Along the seashore the lower pebbly ash of the Aiea section has been folded and slightly faulted. It is covered by an earth or old soil, which can be traced eastwardly directly beneath the tufa of Makalapa, which comes as far west as Halawa stream.

It would seem that this Pearl River series is a combination of marine deposits, reefs, decayed rock, secondary volcanic products, ashes, and solid basalt. The natural conclusion is that volcanic ejections were intercalated with beds of marine origin, illustrated further by the finding of a fine black ash intercalated in the limestone of Fords island, several miles away from the nearest volcanic vent. At present it is not possible to separate them. Passing southerly toward the mouth of the river, the limestones grow thicker and merge into the limestones proved to extend deep into the earth by the artesian bore-holes. The series is of Tertiary age.

Rocks at the Pali

A trip to the Pali gap from Honolulu reveals many points of interest, and the many excavations beyond the gap for a carriage road bring to light phenomena that would not otherwise have been noted. The rocks revealed are the older Koolau basalts, intermediate dikes, and recent flows of ashes and lapilli.

Starting from the city, the first exposures are of the older basalts—vesicular, chrysolitic, agglomeratic—covered by reddish earth, and we



AMYGDALOIDAL BASALT ON THE PALI ROAD, EAST SIDE pass up a canyon whose sides exhibit volcanic layers dipping gently toward the harbor. On reaching the place where vegetation is notably more vigorous, the red earths increase in amount, and are probably in part at least the products of an old crater, not named, a mile or more from the summit. This has been broken down on its southerly side. Nearer to the gap are thick deposits of an agglomerate, having a red clayey cement, which has been cut away at the summit and is very extensively spread out on the eastern side. Its point of ejection is not known. Doctor S. E. Bishop thinks there must have been an orifice at the very notch through which it has been poured out. The notch is being enlarged by removing the old basalt, which is finely exposed in horizontal layers, soon seen, as we pass downward, to have been cut by dikes of a fine grained compact basalt, sparingly spotted by chrysolite.

The photograph, reproduced as plate 5, of the ledges at the extreme southeast angle in the Pali road, three-fourths of the descent down, gives some idea of the relations of several of the different kinds of rock seen. From the carriage to the extreme left the principal rock is an amygdaloidal basalt, containing opal, quartz, natrolite, prehnite, and thomsonite. One mass of quartz, supposed to come from near this spot, is amorphous, with small crystalline cavities, and is about 8 inches in breadth. This is the largest piece of quartz I have seen from any part of the archipelago. This amygdaloid has been cut by several narrow dikes, standing vertically, and traceable down the road for 200 feet. At the angle the walls of the dikes are coated by what looks like obsidian, a quarter of an inch thick. It is a glazed coating produced by the contact of the retaining walls on the igneous mass. The amygdaloid is somewhat columnar. The rough rocks on the right-hand side of the road represent the upper end of a laccolite of chrysolitic basalt, notable for the considerable size and great number of the bunches of chrysolite, as well as by its columnar structure. On both sides of it and above may be seen an agglomerate containing basaltic fragments, and particularly interesting pebbles of chrysolite, which are soft by weathering. At some places it has been cut and again traversed by beds of fine-grained basalt, seemingly the equivalent of the vertical dikes mentioned high up toward the summit of the road. In other places there is a glazing upon the surface of the agglomerate at its contact with a later ash. This ash clinker or lapilli is of a red color, is very abundant, and has been cut by the road in some places to the depth of 90 feet. It has poured down the steep hillside at an angle of 45 degrees, and rests unconformably upon every other kind of rock. It is bright red in color, and is very similar to the ashes of some of the Laeloa craters. It is so obviously of very modern origin that it is strange that any observers should ever have esteemed it the equivalent of the older basalt, and that consequently the divergence of dips was suggestive of a fault between the two. It is recorded in some of my notes that the dike material cuts across the red clinker. Part of the dikes are drab and part of an olive green color. Some of them seem to me to be identical with the chrysolite basalt.

Perhaps these several facts may justify the following conclusions respecting the relative age of the several rocks:

1. The Koolau basalt, in horizontal sheets.
2. Amygdaloidal basalt.
3. Chrysolitic basalt, and some, if not all, of the vertical dikes.
4. Reddish agglomerate with chrysolitic pebbles.
5. Red clinker and the latest dikes.

From the base of the Pali one can follow the course of the red clinker stretching up the sides of the mountain much above the road.

Secondary Craters

CLASSIFICATION

In almost every section of Oahu there are evidences of late volcanic activity as manifested in craters, layers of ashes, tuffs, and dikes. Certain of these phenomena happen to be present in the midst of the settled district, and therefore they are familiar to everybody. When Koolau and Kaala are thoroughly explored others may be added to their number. Geographically they may be grouped as follows:

1. Laeloa series.
2. Salt Lake group.
3. Tantalus and the Pali.
4. Punchbowl.
5. Diamond head.
6. Rocky hill, Mauumae, and Kaimuki.
7. Kaneohe and the Koko heads.

They may be described also as tuff cones, basaltic craters, volcanic ashes, and dikes.

LAELOA SERIES

At the south end of the Waianae mountains is a group of craters, the Laeloa, named from the southwest point of the island. They are Kapolei, Palailai, Makakilo, Kapuai, Kuua, and others not specially named.

Kapolei is a low crater, open to the south on the south side of the government road and north of the railroad, 162 feet above the sea and over 100 above the limestone plain at its base.* The rock is solid basalt with red clinker. There are irregularities in the positions of the layers, so that the normal form of the double quaquaversal dip is not readily seen.

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* It is very near the houses occupied by laborers from California, who are making an experiment as to the ability of white men to succeed in actual work in the cane field.

The surface is rough, without vegetation, and there is a heiau (heathen temple) on the highest point.

Palailai, 470 feet high, lies to the northwest rather more than a mile, in a very important geodetic position, and there is a signal always visible on it. It is a well defined basin-shaped cone, consisting of clinker lava and depressed on the southern side. On both sides of it there may be seen a gray basalt low down containing the spherical nodules analogous to the columnar structure. A mile to the northeast of Palailai there seems to be a volcanic vent, open to the south, with two to three hundred feet of red tuff arranged quaquaversally about it. Some of the layers, consisting principally of hematite, have the appearance of being a separate center of eruption without a real crater. Brown tuff overlies the red.

Makakilo, 970 feet high, a mile and three-quarters from Kapolei, is the next cone in order, and is dome-shaped. It is closely connected with the ash of the supposed unnamed vent just mentioned. The rock at the summit consists of red tuffaceous ash and compact basalt more than usually sonorous when struck with a hammer. The layers dip gently westerly. It has a slight resemblance to a crater, as seen from the next cone to the north. Low down on the east side the drab lavas of the Kaala series appear, overlaid by red ash, which seemed to have a high dip toward the summit of Makakilo, as if there were present the remnants of the eastern rim of a very large crater. This view has not been verified by later visits. Red earth, resulting from the decay of ash, covers both Makakilo and Kapuai.

Kapuai, the next summit, of fully 1,000 feet altitude, lies a mile due north from Makakilo, and is composed of the same ash and sonorous basalt in layers having a low northerly dip. It may form part of a larger rim whose outlines are not now understood. Heiaus grace the summits of Palailai and Kapuai.

The most northern of these Laeloa craters is Kuua, about 1,300 feet high, two and a quarter miles north of Makakilo and 4 miles north from the railroad. It is a well defined crater, falling away on the east side, composed of solid basalt, slightly chrysolitic, and is the largest, best defined, and most northern of the Laeloa series. There is a considerable depression between Kuua and Mauna Kapu (2,740 feet), somewhat north of west upon the Waianae mountains behind. Between these older summits and Kapuai and Makakilo there may be other ill-defined craters, as between Kapuai and Maunawahua (2,430 feet). Red earth and a little red ash rest high up the east slope of Kuua, but the main part of the cone is distinctly basaltic, like Palailai and Kapolei. The other cones between are tuffaceous.

It is generally supposed that the fertile red soils of Ewa plantation have been derived from the decomposition and wash of these craters, aided also by the ejection of volcanic ashes blown southeasterly. This is not the usual direction of eolian transportation on Oahu, but the eruptions might have taken place when the conditions favored such a movement. There is certainly no sign of these ashes on the Waianae side of the mountains. These craters of Laeloa all stand out distinct from the Waianae range, and may be seen in favorable light from Ewa and other localities along the railroad. They are very rarely visited.

SALT LAKE GROUP

The most extensive tuff region is that occupied by three craters, of which the best known is Aliapakai or the Salt lake; the next Aliamau, immediately contiguous, and the third an obscure, inconspicuous depression called Makalapa. All of them together may be called the Salt Lake craters. The area is not less than 12 square miles, from 3 to 6 miles by railroad westerly from Honolulu, and situated at the base of Koolau. Aliapakai was examined by the United States Exploring Expedition in 1840, and was stated to contain a body of salt water nearly a mile in its longer diameter and half as wide. It was only 16 inches deep. In the year following the depth had decreased to 6 inches, and the whole bottom was encrusted by salt firm enough to sustain a span of horses. The surface consisted of cubical crystals in knobs and finger-shaped prolongations. As the lake stands at the sealevel, most authors regard the origin of the saline waters as explained by the seepage of the ocean through the walls or concealed crevices. In the rainy season Brigham says the water is about 3 feet deep, and large quantities of water rush in from the mountains through a hole near the center of the basin (a spring), and the bottom is covered by a blue mud several inches deep. During the dry season the lake contracts to one-third its size. The walls of Aliapakai are 50 feet high on the southern border and 200 on the northern side. The lowest depression is to the northwest, while there has been a breaking down or removal of a large part of the rim on the east, next to the government road. In the lower part of the basin on the south side some of the original coral reef through which the tuff had been ejected is still visible. The tuff contains large and small fragments of basalt of various kinds, with chrysolite fragments up to one foot in length, and there are crystals of augite, biotite, and garnet; also pieces of the coral reef. The chrysolite came perhaps from the source of the chrysolitic basalt described among the rock exposures at the Pali.

To the south and west of the Salt lake one sees large boulders strewn

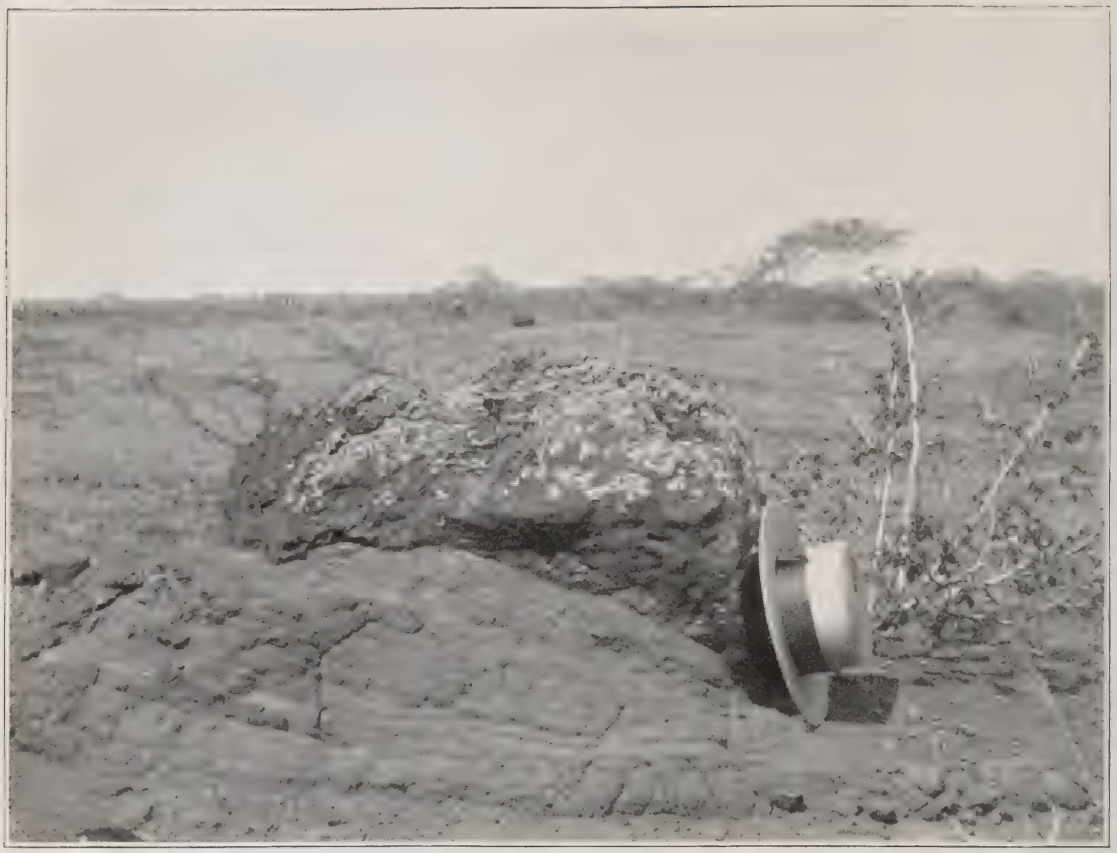


Figure 1.—Lava Block thrown out from Aliapakai

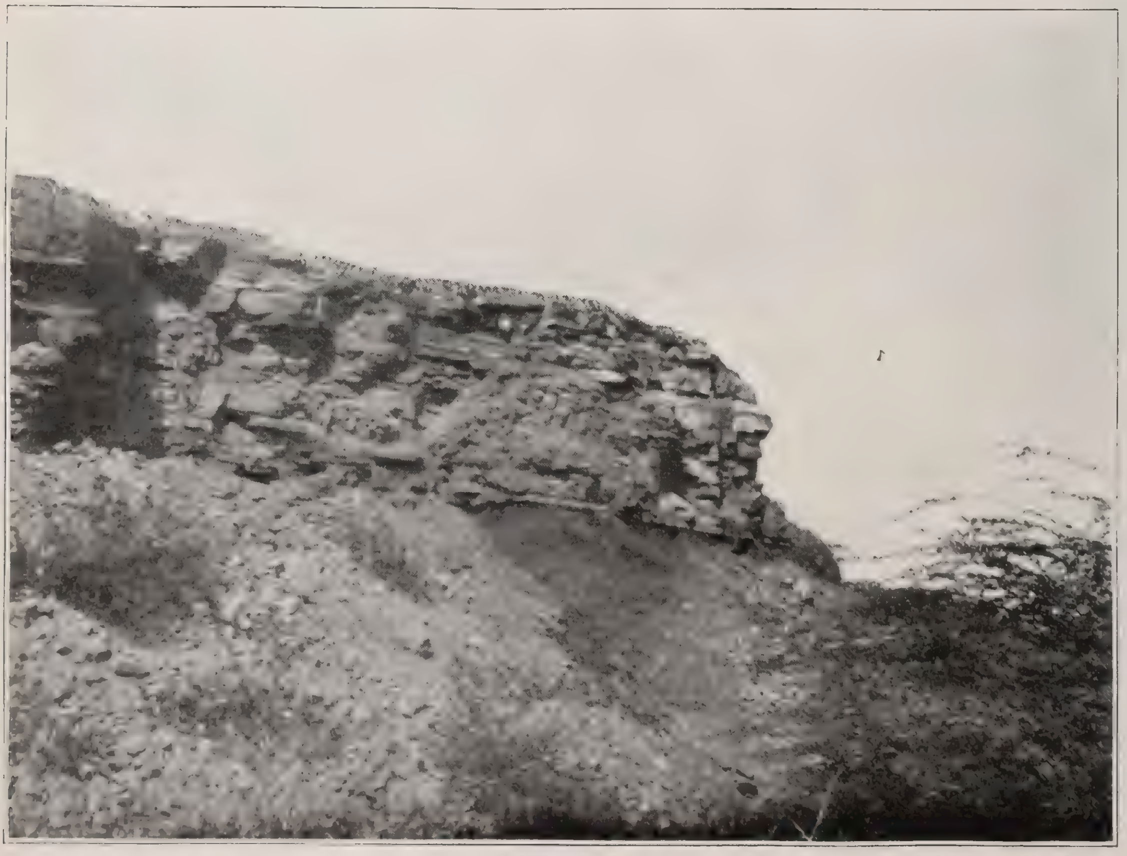


Figure 2.—Tuff near Moanalua Station on Railroad

LAVA BLOCK AND TUFF

over the surface as far as to the railroad, which in certain situations rest on a cushion of tuff, looking just as if they had fallen from the sky on soft mud. Figure 1, plate 6, shows the appearance of such an indentation with its boulder, and others appear in the distance. The largest of the fragments observed in the neighborhood is 8 feet square and 4 feet high. Nearer the lake large stones are imbedded in the tuff, which wraps them in concentric layers, and therefore it is probable that all of them originally occupied similar positions.

Aliamanu is on the north side of Salt lake, and has smaller dimensions, while its base is elevated 50 feet above the sea, and in the wet season may show a large pond of water. More exact measurements make Aliapakai 3,000 and 4,000 feet in the two diameters, and Aliamanu 1,300 and 2,000 feet. The highest part of the circular wall, Leilono, on the north side of Aliamanu is 486 feet above tide water. On much of its bared extent may be seen a conspicuous white coating of calcium carbonate, with limestone fragments and the other constituents mentioned as existing in the Salt Lake tuff. The government road on the east side of these craters has been cut through solid basalt and clinkers that belong to the Koolau range, as also many pebbles and cobbles containing a profusion of crystals of labradorite in the bed of the stream, a branch of Moanalua. Both of the Salt Lake craters exhibit well the usual double quaquaversal stratification, and the dividing rim belongs to both.

Mr Green regards the Salt Lake craters as the oldest of the secondary cones about Honolulu, because of the considerable erosion that is indicated, and this may be well seen in the view from the Pearl City neighborhood. On looking at a large scale map it will be noted that the more western branch of Moanalua stream was dammed up by the Salt Lake outflows, and consequently the water has been forced to cut its way through them, excavating a canyon more than a hundred feet deep. Portions of the tuff now lie on the eastern bank, resting on the Koolau basalt. The part deeply excavated is not quite a mile in length. This western branch joins the eastern above Moanalua station, and the enlarged stream continues to the sea through a broad plain, in the direction of the latter valley. The low plain is half a mile wide, now occupied by rice fields, and its whole area was once occupied by the tuff, because it constitutes the promontory on the east side. The upper part consists of large rounded pebbles underlaid by an earth exhibiting fossil plants on the road east of the Pacific guano fertilizer establishment.

Professor A. B. Lyons calls attention to a fine grained sandstone which originated in connection with the building up of the Salt Lake craters. The material was brought down the Moanalua stream, consisting perhaps of fine particles blown out of the crater, which were carried by winds and storms from their source, filling the valley, and were deposited lower down. These leaf beds are elevated about 20 feet above tidewater.

SECTION NEAR MOANALUA

A more detailed study of the relations of several deposits is possible in the bluffs less than half a mile west from Moanalua station along the railroad. The first exposure is of a raised limestone, containing marine shells and broken corals, apparently declining beneath earthy tuffaceous beds in a westerly direction. Following the bluff, after a gap in the continuity, there is an excellent exposure for many rods where fresh excavations have been made for the railroad. It shows even better now than when photographed (plate 6, figure 2). The bluff is estimated to be 40 feet high. The lower portion is an earth or soil existing before the eruption from Aliipakai, for trees grew on it and were not consumed at the time of the eruption. Their stems stand upright in the tuff, as may be seen by a scrutiny of the figure. This upper layer may be 10 or 12 feet thick and the stems can be seen along the whole length of the bluff, some of the holes being a foot in diameter. It is easy enough to imagine the scene. There was a forest growth on the soil of the lower part of the section. Showers of sand and stones covered the forest 10 feet deep, occupying the spaces between the stumps, and in the course of years a new soil accumulated and vegetation assumed its sway on the surface of the tufa, and the impressions made by the stubs remain, either hollow or filled by miscellaneous mud. They are like the upright tree-casts found in the cliffs of the Joggins, Nova Scotia.

Following this bluff to the west, one notices that the tufa sinks down in small waves, due to the giving way of masses of the loose soil beneath. Near the west end of the bluff both the tuff and soil appear, and the latter is underlaid by a coral reef 8 or 10 feet thick. This is underlaid again by tuff, as seen under the iron rails, and toward the sea there is coral again. Hence the succession, as indicated here, is:

1. The main coral reef.
2. Thin layer of tuff.
3. Coral reef or limestone.
4. Decomposed rock sustaining a soil covered by forest.
5. Eruption of tuff from Aliapakai covering the country from the promontory east of Moanalua to Puuloa and beyond.
6. There may be added a long interval of time during which the gorge in the upper Moanalua stream has been excavated.

As one follows the railroad beyond the bluff he can see the long gradual slope from Aliapakai extending indefinitely toward Pearl river. The rocks come to the surface everywhere. Beyond Puuloa station there is an extensive cut in the tuff, showing 10 or 12 feet of the tuff in a fresh condition. The lower part is fine grained, 8 feet thick, the upper a coarse sandstone, almost a conglomerate, 2 feet thick, with 4 or 5 feet thickness of sandy beds at the top. It is a palagonite, a tuff somewhat altered by heat and moisture, with a distinct resinous luster. All the tuff cones of this region are composed of this rock.

MAKALAPA

Between Puuloa and Halawa stations is a promontory of palagonite, around which the railroad makes a long curve, but will shortly take a new course cut through the rock. Coral limestone full of shells and polyp structures rests on and is intercalated with the tuff along the railroad in both cuts to the height of 15 or 20 feet. The finest examples of tree stems seen anywhere along the railroad appear in this cut. One of the stems measured 15 feet in height, penetrating both the fine and coarse tuffs.

Climbing the bluff, there is an upward slope for half a mile to the crater of Makalapa, perhaps 80 feet above tidewater. The pit is not seen till you stand close to it—a very pretty basin, an eighth of a mile in diameter, broken down on the southwest side. The tuff contains various basalts, lavas, limestones, and corals of all sizes up to 4½ feet in diameter strewed on the surface like those figured near Salt lake. Some of the limestone fragments have been affected by the heat so as to have become partially fused. At the west end of the new railroad cut the soil crops out beneath the tuff, evidently continuous beneath both the Aliapakai and Makalapa flows. The tuff thins out and disappears at Halawa stream, but the soil increases in amount and merges into the layers already described at Aiea. It is noticeable that the strata are depressed at every small valley traversed, presumably because of the removal of the soil beneath by aqueous action. The eastern branch of Halawa valley was cut off by Aliapakai, precisely as was the western branch of Moanalua. The island Kuahua is also composed of tuff, 20 feet thick, exposed. Evidently this was once continuous with the same material upon the mainland.

TANTALUS SERIES OF CRATERS

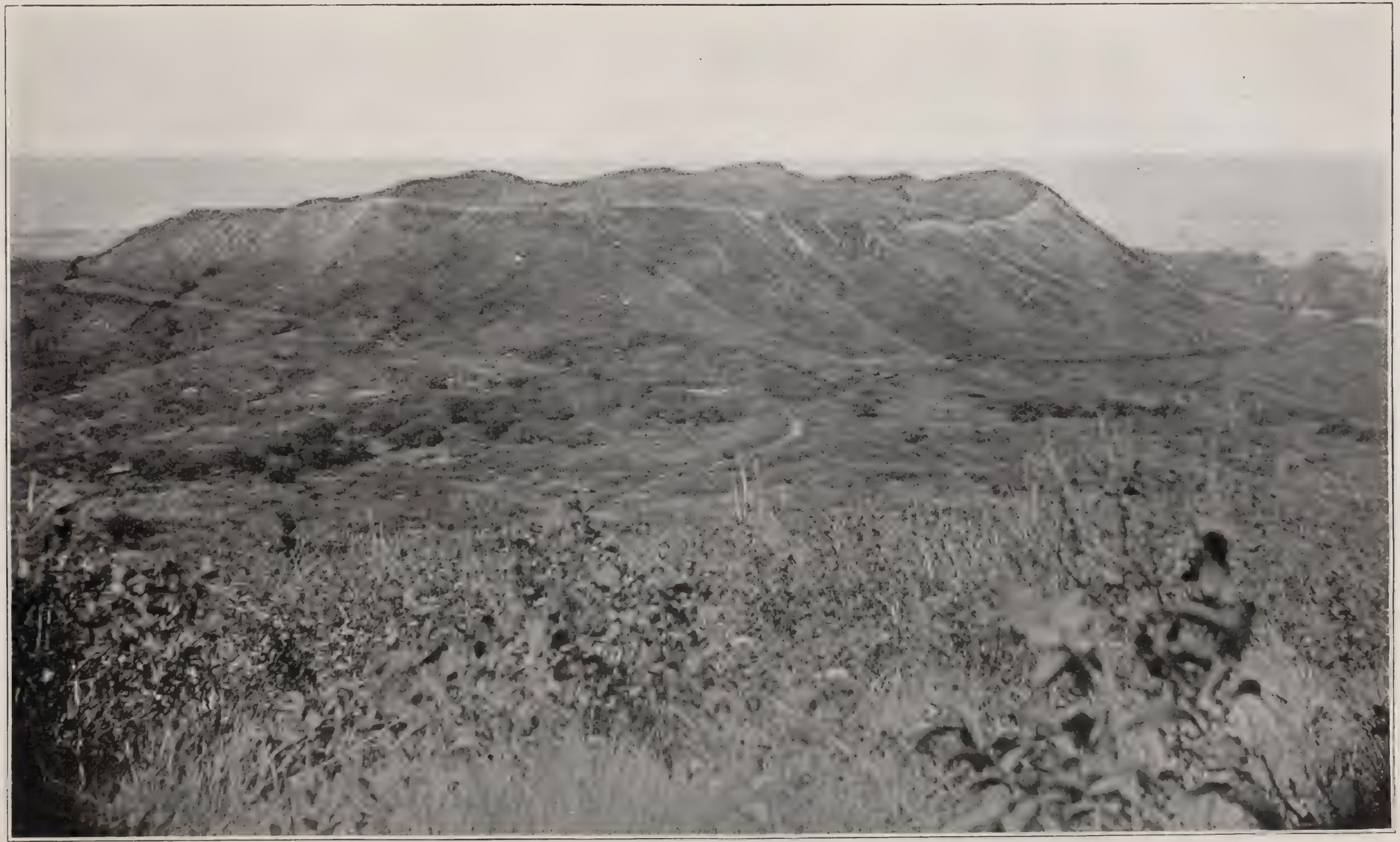
A road with easy grades starts from both sides of Punchbowl, zigzags up a long slope covered by eucalyptus trees planted under governmental authority, and finally reaches the base of the volcanic cone called Tantalus by foreigners and Puu Ohia by the Hawaiians, whose summit is 2,013 feet above the sea. The crater has a level top, over a quarter of a mile in diameter, 400 feet high, with the breakdown on the southeast side. It is covered generally by a thick matted mass of grass, and the eastern part of the crater by tree ferns. The rock is rarely exposed, being a basalt very much softened by decay. The underlying rock has been softened down to a clay. The depth of the basin is estimated at 250 feet below the rim. The immense mass of coarse black ash at the base of the cone and all along the carriage road above Punchbowl make it probable that it was one of the products of eruption from Tantalus.

Tantalus is situated upon the west slope of the Koolau range, 1,600 feet above the sea, and is probably only one of many others similarly located in the unexplored region. It is also to be compared with the source of the red-ash clinker deposit mentioned in the description of the Pali phenomena and the small nameless crater a mile west from the Pali summit. Being quite near Honolulu and reached by an excellent carriage road with low grades, it is becoming a place of much resort for pleasure and soon of residences. One of these little known craters is mentioned by Brigham on page 17 of his "Notes":

> "At the head of Punaluu valley is a large cone crater from which radiate several valleys, as the Kahana, Kaliiwaa, Punaluu, and others. This crater is densely wooded, and occupies nearly the center of the range. No one seems to have ascended it, and it is impossible to say how deep the cavity may be, but the internal slopes as seen from below seem to be quite steep, and probably the outer wall is broken down. Soft red clinkers are found in the stream at Kaliiwaa."

PUNCHBOWL OR PUOWAINA

This is a tuff cone on the edge of the city of Honolulu, and is situated at the base of Koolau Poko, very nearly in the outlet of Pauoa valley. It is 498 feet above the sea, and rises from the edge of a plain 40 or 50 feet high. The spread of the cone is just a mile. The top is 2,200 feet in its longest and 1,800 feet in its shortest diameter. The depression of the bowl is about 150 feet on the southeast side, and a considerable chasm has been channeled out by the descending waters accumulating in the basin. Good carriage roads ascend the hill from both sides, uniting in the saddle on the northeast side at a height of 263 feet, and then curving around the east side so as to pass through the lowest point in the rim. It is an excellent place from which to see not only the city but most of the localities of geological interest. Most of the year the sides of Punchbowl are covered by scanty, parched vegetation, as there is no reason for its irrigation. The rock is tuff, with a resinous luster or palagonite. Being frequently yellowish brown in color, Professor Dana says the color is evidence that the temperature of the water was below 200 degrees Fahrenheit when the beds were deposited. The structure is clearly that of the normal volcanic cone, the strata dipping quaqua-



PUNCHBOWL FROM TANTALUS

versally inward from the exterior rim and similarly outwardly from the edge of the crater. The best place to examine the beds is at a quarry at the southwest base below the reservoir. A space as much as 500 by 400 feet has been excavated to the depth of 40 or 50 feet. Many irregularities in the dip are exhibited, particularly two upward bulgings with small faults. Photographs show this imperfectly. Nearly vertical seams are lined with a calcareous incrustation, originating presumably in connection with the outburst through limestone. A few spherules of thomsonite occur and fragments of vesicular basalt. An artesian well at the Queen's hospital has penetrated through this tuff, showing an extension of the volcanic mud in that direction. The underlying material of the plain seems to be shown in a pit on Vineyard street, where there was exposed 15 feet thickness of earth with rolled pebbles and marine shells. At a quarry 1,000 feet east from the one named, there are layers of a black, compact rock, perhaps a finer mud consolidated. Interesting sections showing the relations of the cindery ashes to the tuff will be described later.

At the upper side of the reservoir is an interesting dike cutting the tuff vertically and underlying the ashes. It is a basalt slightly chrysolitic, 3 feet wide, running in the direction of the summit, and with two others mentioned by Brigham near the ravine, one 2 and the other 10 feet wide, now covered by debris, have cut the tuff radially. The reservoir dike shows differences between the outer and inner portions, that on the outside being finer grained and the inside a breccia. Both are vesicular. There are joints parallel to the walls, some of them coated with lime. About 10 feet of the dike are clearly exposed here. Seventeen hundred feet lower down in the direction of the dike, at the pumping station, there has been a recent volcanic ejection of red clinker, a sort of blow-hole, not unlikely connected with the filling of the chasm. At the summit of the road, where it winds around a flag-staff close to the battery, there are fine exposures of the black cinder ash, with included nodules, red clinker, and compact basalt, slightly porphyritic, by black crystals of pyroxene. The whole interior of the basin is covered by loose black ashes, weathered to brownish red at the surface. In Dixon's "Voyage around the World" there is a picture representing the Punchbowl in 1786. In the sketch the eastern part of the rim is the highest, much as it appears from Rocky hill at the present time. Plate 7 represents Punchbowl as it is seen from the east from a higher elevation. The drainage outlet is at the extreme left.

DIAMOND HEAD OR LEAHI

This is the most perfect, as well as the best known, of all the secondary craters about Honolulu. Visitors recall it as the prominence seen just before reaching port from the east, and again upon resuming their voyage. Artists have vied with one another in efforts to display this beautiful hill on paper or canvas, and every one is interested in viewing the channeled water-courses upon the outside and the barren rocks as contrasted with the rice fields, cocoanut groves, and the green plain of Waikiki, a health resort, close to the city at its base. It is a truncated hollow cone, 4,400 feet in the greater diameter of the rim, and 4,300 in the shorter diameter. The elongation is in the direction of the trade wind, and consequently the southwest side is higher and thicker than its opposite. This fact, first stated by W. L. Green and reiterated by all later authors, applies to many others of the secondary craters as well and to the direction of the spread of the eolian beds. The southern highest part is 761 feet above the sea at its base, the opposite end being somewhat lower, and there is not much variation in the rim elsewhere. Inside, in the wet season, there is a pond at the lowest point, 200 feet above the sea, as near as may be to the eastern wall. From the outside Diamond head looks like a solid hill, and with its reddish tint and apparent strata is very suggestive of buttes in the Chalcedony park of Arizona.

The diameters of the base of this crater are 5,000 and 6,000 feet respectively, making the seashore the extreme southwest limit. The tuff has been recognized in the very deep well sunk by James Campbell near the seashore at Waikiki. Two hundred and seventy feet of tuff were penetrated by the drill beneath 50 feet of beach sand and gravel. The diameter of the base may not be extensive enough, since the tuff crops out at Kupikipikio nearly three-quarters of a mile easterly from the rim of Diamond head.

The structure of this cone is typical of its class—a broad, shallow, saucer-shaped crater, with layers dipping toward the center inside, and outside outwardly in every direction at angles of 30 to 35 degrees. It would seem that the mud was forced directly upward from the center, the surplus flowing over the outside of the cone in every direction, and after the supply had ceased to come the inner portions fell back toward the vent. The fragments consist of every variety of the older basalts, with much limestone, corals, and shells that were torn off by the ascensive force of the eruption from the coral reef beneath. Mr Green suggested that some of the lime came from the evaporation of ocean water. Nowhere is the lime more abundant than it is here among the secondary craters. It has been dug out and used for chalk in the early days of the settlement. The tuff has been much exposed to the elements, and is consequently very friable. It is a palagonite like that of Punchbowl. Professor Dana says that since 1840 the highest part of Diamond head "has lost something of its boldness" by erosion. W. T. Brigham says on page 20 of his "Notes:"

> "In the winter of 1864, during a severe rain, when 36 inches of water fell in a week, a deposit of mud 2 feet in depth was formed over the inner basin, and the degradation of the exterior was still more extensive. The southwest end, which is the highest point, was formerly quite accessible, but can now [1867] only be scaled by ladders or ropes."

It was quite easily climbed in 1883 and is at the present time, as is evidenced by the fact of its ascent by thousands of soldiers in their brief sojourns at Honolulu en route to and from Manila. Mr Brigham thinks the summit is now (1899) 25 feet lower than it was when he first explored it, more than 30 years previous.

The relations of Diamond head to Kaimuki, the next volcanic cone inland, are very clear. The basalt of Kaimuki clearly overlies the tuff in the notch between the two craters. Its superior position is apparent for several rods, and the tuff has evidently been affected by the heat of the basalt. The relations are still better seen at the promontory east of Diamond head called Kupikipikio, which owes its existence to the thick basaltic flow which covered the tuff over many acres of extent. The tuff is capped by fine black ashes from 9 to 10 feet thick, thought to have come from Diamond head, because in the spot nearest that summit they slope away from it. No signs of this ash have been recognized on the leeward side, probably because of the prevalence of very low ground and of the ocean. The greatest distance of carriage on Kupikipikio is not quite three-quarters of a mile from the eastern rim of Diamond head. The upper part of the ash has been weathered to a reddish brown color and covered by the basalt; so the section is very clearly tuff at the base, ashes both unaltered and weathered, covered by basalt.

It may be well to describe here the interesting basaltic dike, perhaps of later origin than the ash beds, as they seem at one place to have been disturbed by its ejection. Quite near the last house on the seashore, coming easterly from the lighthouse, is a fine exposure of a basaltic dike from 3 to 6 feet wide, forming a cliff 25 feet high, exposed to the sea. It is very nearly vertical, possibly inclined 80 degrees northeasterly. Its course by compass is north 50 degrees west, running toward Diamond head. Farther on, this dike has cut the coral reef for several hundred feet. It stands apart by itself, the softer limestone having been eroded by wave action, and it looks like the foundation wall of some building. The outside of this exposed dike is compact, next its boundary walls, and the inside is composed of spherical pieces of basalt, with concentric structure inside. Petrographically it resembles the Kaimuki basalt.

Professor Maxwell says the limestone here has been altered to gypsum. At Kaena point I found ledges where a basalt had penetrated the coral limestone and indurated the calcareous rock with included *cypræa*. Hence we have the evidence of a very late volcanic eruption at localities very widely separated, upon Oahu.

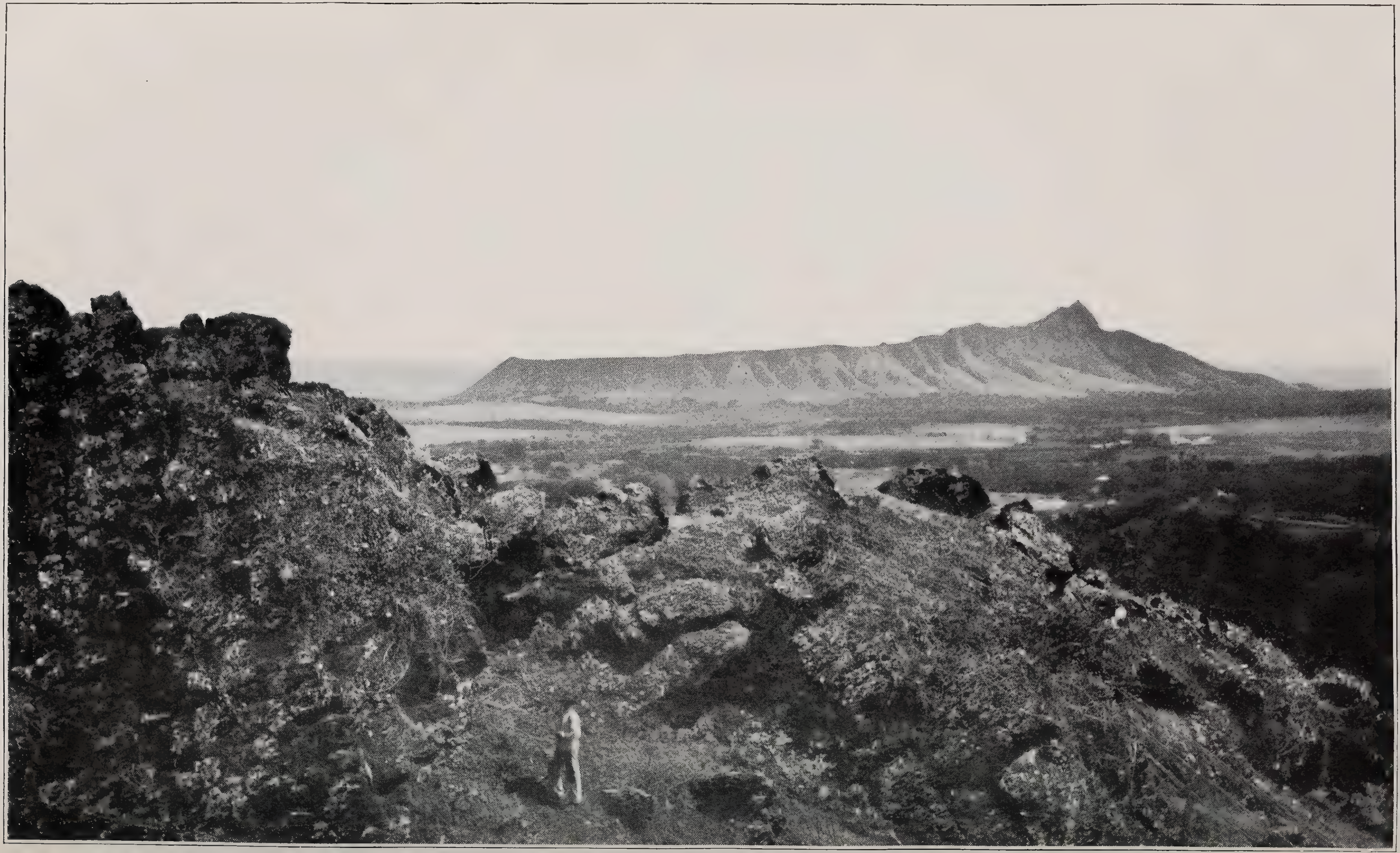
Plate 8 represents Diamond head as seen from the summit of Punchbowl. Maxwell says the slopes of Diamond head and Punchbowl are white with deposits of silica and carbonate of lime, etcetera (page 39).

ROCKY HILL, KAIMUKI, AND MAUUMAE

Three basaltic craters, quite near each other and within easy reach of Honolulu, remain to be mentioned, and the facts should be placed upon record before the extension of the city shall have obscured their present topography.

Rocky hill lies just east of Oahu college, in Punahou, blocking up Manoa valley. Its height is 297 feet above the sea. The rock is a clinker, weathering roughly. The crater has been broken down on the side toward the college, and the eastern wall must be more than 100 feet high. The slope toward Manoa is mostly smooth, the rough ledges having been covered by thick deposits of the black cinders blown down from the Tantalus craters. At the highest point in the road between Rocky hill and Round top is a very large dike of basalt that has been quarried for building stone and road metal. The central portion is compact, with few jointed seams. On both sides the material seems to possess the same character, but is traversed by many columnar jointed seams dipping westerly and quite contrasting with the central mass. Still outside there are multitudes of the spherical columnar stones imbedded in reddish clayey cement, and they seem to be a part of the dike, making a width of 70 or 80 feet. The point of contact with the adjacent Koolau basalt is not seen. The fact of the existence of a ridge having the direction of the dike from Rocky hill to the base of Round top, and the dike being on the divide itself, suggests its derivation from the crater. The rock all the way to Wilder avenue from the summit, consisting of drab and dark brown compact or vesicular, often chrysolitic basalts, is probably a part of the Koolau series. Along the road there are bunches of hard rock, encircled by red friable cement, that represent probably the ordinary decay of the older rocks.

There is a quarry in the basalt at the end of a tram road to the west of the Moiliili church where very much rock has been excavated. The material is now used for road metal. The limestone occupies the low ground in front, and in the seams of the rock are many films of calcium carbonate and silica, indicating the presence beneath of the reef. It is



DIAMOND HEAD FROM PUNCHBOWL

surmised that this rock came from Rocky hill, as there is a slope from the crater to the quarry and to the church. There are several masses of cinders interrupting the continuity of the basalt, which are suggestive of blow-holes and steam vents. Amygdaloidal and zeolitic minerals occur at the quarry. Phacolite and laumontite have been identified among them. Calcite and amorphous silica are also present, the latter on surfaces several square feet in extent in rudely parallel lines. The bluff is traversed by small veins full of nephelite, granular melilite, and augite. Either of these minerals may form a layer of crystals, closely crowded together, all standing vertically to the plane of occurrence. Veins three inches wide or less abound in these minerals, mixed with a multitude of acicular crystals of kaliophilite. Mr Wirt Tassin has identified these species. This is the most interesting mineral locality seen anywhere on the island.

Kaimuki is the small crater north from Diamond head, 292 feet above tidewater, otherwise known as Telegraph hill. It was first described and figured by Dana in the exploring expedition report. Kaimuki and Mauumae are both represented in that report as beautifully rounded craters, by the side of Diamond head; but no one could find them now if he were obliged to discover cones as handsome as those there delineated. Kaimuki is estimated to be about 900 feet in diameter, 50 feet deep, and somewhat depressed on the side toward Diamond head. On the other side a sort of blow-hole has brought forth a large amount of brick red and gray clinker. The chief flow has been toward Moiliili church. It is a solid basalt containing much iron, as is proved by the red earth, produced by disintegration, lying on it. A certain block is pointed out by the side of the road which sounds like a bell when struck by a hammer or stone. This particular block is especially sonorous because it does not rest securely on the ground.

The road east from the church passes between Kaimuki and Mauumae, and the lowest point in the divide will represent the meeting place of the lava from the two craters. Real estate agents are opening new streets across this northerly slope, and some quarries are furnishing stone suitable for building purposes. Some of it is amygdaloidal, and probably the minerals found will be like those in the quarry on the other side of the old church. This lava has spread itself over the coral reef at the base of the flow on the Waikiki side; on the other side it reached to the older Koolau basalts, blocking up the Palolo valley, so that the stream had to change its course—excavate a canyon for itself—and join the Manoa river, which had been displaced by another flow. The united river flows to the sea at Waikiki, across extensive rice fields. It is easy to see the limits of the Kaimuki flow on the Koolau side of the canyon.

On the east side, toward Waialae, the flow has been equally extensive.

The division line between Kaimuki and Mauumae is not well marked, but for practical purposes may be placed at the lowest line between the two not far from the road over the hill. Excavations show all sorts of lava with clinker. Passing to the summit one sees quite a number of lava bombs of small size strewn over the surface. The rock is mainly compact basalt with more or less clinker. It is higher than Kaimuki. Standing on the summit the west side is seen to be very abrupt, and the break-down is toward Waialae. With the bombs are rough fragments that were plastic at the time of eruption, and many stones, up to two feet in diameter, that must have been ejected at the same time. Some of the seams are lined with lime, suggesting the contiguity of the coral rock underneath—the same that underlies the Kaimuki flow on the "white road"—and which has been pierced by the drill in the borings for artesian wells between the continuation of Beretania avenue and Waikiki.

KOKO HEADS

The eastern and highest Koko head is almost the first bit of land seen by the traveler from the east en route for Honolulu. It is a very well defined volcanic cone 1,200 feet high, 6,000 feet long, or 7,000 in a northwest-southeast direction, and broken down on the east. The inside of the crater is 1,500 feet in diameter from north to south, and 100 feet less in the east-west direction. The ascent is gradual from the sea to the floor of the crater, commencing with some flat lands that may have been of marine origin. It looks as if one could drive a team with ease from the seashore to the inside of the crater. The Hawaiian name for this eastern head is Kokelipelipe.

An examination of the north side shows it to be composed at the surface of ashy beds, very friable, dipping 25 degrees, corrugated by narrow ravines down which large blocks have fallen. There are no fragments of basalt among them. The underlying beds are of palagonite of yellowish color. Near the border the dip is much smaller, approaching horizontality. The tuff can be seen to overlie the Koolau basalt for a distance of 300 feet. Some small portions of this tuff may be compared with a cobbly conglomerate; the most of it is not coarse. The facts of superposition are revealed by erosion against a ridge connecting Koko with the Koolau range.

From the west the structure is clearly seen, the slopes being steep, too much so for comfortable climbing, and the upper layers at the angle have been denuded, showing a fine anticlinal, with the dip varying from 45 to 60 degrees. The outer layer is of ashes, the inner yellow conchoidal tuff. This tuff is continuous around the south side of the cone. At the southern base it is covered by black ashes. Large fragments of compact chrysolitic basalt are found close by, which have probably come from openings, dike like, near the base of the cone. Lines of these fragments extend across the space between the Kokos and up the slope of the western head. Pieces a yard across rest upon the tuff. Further examination will probably reveal the presence of dikes like that on Kupikipikio.

None of the secondary craters thus far discovered surpass the eastern head in the clearness of the double quaquaversal dips. Between the two Koko heads is a circular hole, 800 feet across, which looks like a small crater. The beds dip away from it on all sides, and the walls are stained by a white incrustation.

The western Koko head is 9,000 feet long, 5,500 feet wide, including the possible crater just mentioned. The eastern portion is a long hill, from 200 to 300 feet high, with numerous blocks of limestone on its surface. It is composed of tuff, capped by ash beds.

Hanauma is a circular bay in the center, 2,500 feet long and 1,750 feet wide, which seems to be the central crater, now entirely worn away on the side toward the ocean, and the dips quaquaversal about it. The highest point near the western end is called Kuamookane, 644 feet. The dip here is toward Hanauma on the inside, but to the southwest toward the outer side of the head on Kawaihoa. Brigham speaks of a small crater, covered with grass, on the west side of Hanauma, and also of blocks of lava on top of Kuumookane, which he suggests may have been carried there by Hawaiians in ancient times for monumental purposes.

Both Koko heads are more or less covered by a deep red soil, showing that a long time has elapsed since the craters have been active. For 3 miles the seaward sides of these heads are precipitous, because of the action of the ocean. Interesting inscriptions and burial caves are reported recently as found on the greater head.

I was unable to visit the craters on the Kaneohe peninsula. They are said to be composed of tuff.

Black Ash

The city and environs of Honolulu are widely covered by a coarse black ash or sand of volcanic origin. It is so coarse and uniform that it has been utilized for the removal of all sorts of sewage from the houses to the sea. When the population was sparse this material rendered the laying of cement pipes unnecessary, as it removed the waste matter in a satisfactory manner. Now that the population has greatly increased, there is a call for an improvement over this primitive method of drainage. Nevertheless, facts about the distribution of this ash will still be of importance, as it will be years before all parts of the city can be reached by the new sewers.

The extreme northeastern limit of the black ash is at the base of the Tantalus cone, where it is well exposed along the road for a quarter of a mile. As much as 25 feet thickness of it is presented to view here. Some of it is weathered, and there are numerous small nodules scattered through it, varying in size from grains to a length of two inches. Some parts seem to be consolidated lumps, both black and red. This material lies at the southeast base of Tantalus, just as if it had been discharged from the crater above. Following the road downward, these ashes appear again, perhaps continuously, at the very southwest base of the cone, rising 40 feet above the road. Here they cease, for the ridge is only just wide enough for the road, and the loose material would have been shed, as it fell from the air, like gravel from the steep roofs of a house. The ash reappears above a reservoir, and, except at a spot about 1,000 feet high, it continues through the eucalyptus forest down to the lowest great curve in the road on the spur of the mountain, about 500 feet above the sea. It is wanting between this curve and Punchbowl, but it is continuous down to the Lunalilo house, on the eastern slope of the spur. I did not observe any of this sand on the more western spur from Tantalus.

The spur running down to Kakea and Roundtop toward Makiki is covered by this sand, to the obscuration of the underlying rock, nearly all the way from Tantalus. A small pond east of Kakea, seemingly an old crater, is sometimes spoken of as the source of the great flood of ash, as it is continuous from it over the top of Kakea, 1,460 feet high, and all the neighboring summits. All these hills have rounded slopes, as if they had been deluged by showers of sand. It poured down the Manoa slope as far as to the residence of Mrs S. N. Castle. Roundtop, 1,062 feet, is overlaid by the same material, and everything is covered down to Wilder avenue and beyond. The road from Punahou up to Manoa valley and the north side of Rocky hill shows it nearly everywhere. From Oahu college along the base of the hills sloping down from Tantalus and around the base of Punchbowl the amount of this ash reaches its maximum thickness.

The following statements give the thickness of this material as found in sinking artesian wells, none being mentioned east of Punahou. At the Woodlawn dairy, corner of Bingham and Alexander streets, there is 10 feet of soil, 20 of sandy clay underlain by 20 of black ash. At the ice works, one mile west, there are 10 feet of ash under 4 feet of soil.

Nearer the sea the ash is 6 feet under 4 feet of soil. At Thomas square, 6 feet under 6 feet of soil; at the pumping works the ash is 10 feet; at the Government (Palace) yard, 4 feet under 4 feet of soil; at J. B. Atherton's, King street, 12 feet of ash; at the Queen's hospital, 10 feet. On Vineyard street an excavation shows 10 feet of ash over a marine deposit. On Hotel street, next the Library, about 4 feet of ash have been revealed by recent excavations. Many other localities have been noted in recent excavations between the turn from King street to Waikiki to Nuuanu stream.

Much may be learned by studying the phenomena presented about Punchbowl. First, however, it must be stated that this material is used much for grading and filling holes in the roads, and about buildings. Soon after its application it becomes rusty, and in a year or two the color has completely changed, so that it is not recognizable. The reddish color of the road and the sidewalks all over the city indicates its presence to those who understand what the black ash may become, and its pulverization gives rise to the dust so freely blown by the trade winds into one's face all over the city. A very prolific source of it is from the slopes of Punchbowl, where it may be seen in abundance, both in the original and altered conditions. At the "Battery," on the summit of the road, this ash occurs in connection with scoria, lapilli, and basalt. It is apparently the throat through which there have been copious discharges. The greater part of the inside of the bowl is covered by it, and those who believe the whole material came from Tantalus would say it had rained down into the bowl from the sky. Nearly opposite the lowest point in the rim of the bowl there is a hill (197 feet) known as the "Powder Magazine," entirely composed of this sand, said by some to have been blown out there from Punchbowl. While this may be true, it is not necessarily so because of excavations of the ravine between the Magazine and the Bowl by running water. Near the upper end of this ravine there is a great ledge of these ashes compacted together and sloping downward as much as 35 degrees. There is an appearance of sliding over tuff in this ledge. Lower down the ravine the sand is overlaid by a thick deposit of pebbles and cobbles. Other locations of the sand superimposed on the tuff may be seen between the powder magazine and the reservoir (120 feet). Just below, at the quarry, the several beds are well shown. There is first the tuff at the base, with its surface decomposed, the result of a long exposure to the elements. A soil was thus formed. Above this soil appears the black sand, fully 25 feet thick, and the surface of this substance has changed its color by weathering and allows the growth of existing vegetation on it. In the sand there are often columnar and root-like concretions, sometimes mistaken for vegetation.

The most westerly exposure of these ashes is at an old cemetery between the Insane asylum and the Bishop museum. Obviously the Nuuanu valley may have been filled with this deposit, which has nearly all been removed by fluviatile erosion, leaving this remnant of one or two acres in extent. This may be 10 feet thick, as shown by excavations, with caves and pillars of a similar material made to cohere by concretionary attraction. Here may be seen the pebbles overlying the ashes. They have been seen also on the north side of Punchbowl. Hence there are three localities of stones thrown out from Punchbowl subsequently to the discharge of the ashes. It is to be noted that the ashes at the crest of Punchbowl near the flag-staff and those below Tantalus and over Roundtop contain numerous nodules. These are not present in the deposit in the lower grounds about the city. Perhaps their greater weight explains why they are limited to locations near their point of departure.

My conclusion in regard to the origin of this coarse black ash is that it probably originated in at least three craters—Tantalus, the pond east of Kakea, and Punchbowl. The other shore craters, Diamond head and the Kokos, have poured out freely a similar but finer grained material, and Makalapa may have been the source of the consolidated ash plant beds near Halawa. I have also found the same substance intercalated in a limestone on the shore of Fords island. Reference has been made elsewhere to red ashes discharged from the Laeloa craters and from secondary openings on Koolau.

ROCKS OF THE BASALTIC AREAS

There is little variety in the rocks of the older igneous areas on Oahu. All of them are basalts, consisting of the common mixture of augite and plagioclase, usually labradorite, with a slight sprinkling of magnetite. Chrysolite is very common. The basalt may be compact, fine grained, coarser grained, vesicular, scoriaceous, and it occurs also in every stage of decay. In general these rocks correspond with those on Hawaii described petrographically by E. S. Dana.* I will mention a few general facts about the occurrence of these varieties at specific localities.

At Kaena point the basalt has been cut by a large dike, 11 feet wide in the railroad cut. Of this the outer 3 feet on each side are slaty, because of joints parallel to the sides, and the inner 5 feet, with a few horizontal joints, correspond better with our usual notions of the appearance of basalt. Southeast from this first exposure the dike becomes larger—13 feet of the slaty mass on one side, with a solid core of 8 feet thickness. It may be followed readily for a quarter of a mile along the railroad. Some of the vesicular lava weathers white and loses a part of its substance, so that it seems almost like pumice. The cliffs by the side of the railroad consist of thick horizontal basaltic beds cut in several places by small vertical dikes, especially at Makua, which are chrysolitic. All these dikes seem to trend in the direction of Kaala.

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* Characteristics of Volcanoes, pp. 318-354.

On the Oahu plantation the vesicular lava is of two kinds, one with large irregular cavities and the other with rather small spherical bubbles of uniform size, equally distributed through the mass. Doctor S. E. Bishop thinks these varieties are characteristic of the Aa and Pahoehoe lavas, as he has observed them at the typical localities on Hawaii. This suggestion accords with what I have seen and is accepted for a working hypothesis, and emphasizes the opinion that the volcanic phenomena of Oahu, Hawaii, and all the islands are identical throughout.

East of Bishop museum there is much chrysolitic basalt in ledges that have been quarried. One opening shows an immense columnar mass of a compact gray basalt, which represents the filling of an old lava conduit, and would therefore be more modern than the surroundings. These old tunnels must have been commonly filled up on Oahu.

Near the head of the Palolo valley is a dike crossing the valley, nearly 60 feet thick, and running parallel with the Koolau axis. The constituent minerals are more crystalline than usual, as the mass seems to have cooled slowly, without any vesiculation. It has a specific gravity of 2.90, according to W. L. Green, who has used this rock as the text for a discussion of the relations between basalt and clinkstone.* Its peculiarities, according to him, are the absence of chrysolite, incipient crystallization of the labradorite and augite, light color, low specific gravity, and a subcolumnar structure. Mr Tassin finds a nephelite-melitite basalt among the specimens brought from the Moiliili quarry cited above, page 46. This is not the same as the nephelite basalt described by Wichmann in "Ballast from Oahu," 1875.

The most interesting subject concerning the basalts is their decomposition. Some reference has been previously made to it. A genuine basalt is by decay changed to a mass of nodules cemented by a reddish clay substance. This might easily be mistaken for a lava flow of different age and character, whereas it is only decomposition. Examples of it are common, as at the Ewa church, Oahu plantation in the gulch, near Oahu college, ascending the hill to Manoa valley, etcetera. After the production of a clayey cement the transition to beds of sedimentary origin is easily consequent, since streams of water will remove and concentrate the silty material, and thus is formed the kaolin to which allusion has been made. This subject has been treated in a masterful way by Doctor Walter Maxwell for the Hawaiian islands, to whose work the reader is referred for full information.*

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* Vestiges of the Molten Globe, part II, p. 135.

Fossil Land Shells

At the western base of Diamond head I have gathered many specimens of the genera *Achatinella* and *Helix* in a breccia consisting of tuff cemented by calcium carbonate, the latter mineral having been derived from the underlying reef when the tuff was ejected. The order of genesis is:

1. The deposition of the coral reef upon an ancient lava.
2. The ejection of tuff through an opening in the reef produced by seismic action, probably starting in shallow water and bringing up samples of the lava and limestone.
3. The crater of Diamond head supported vegetation on its flanks above the sealevel, and while thus situated fragments of the volcanic rock rolled down the steep sides, water washed the lime into the talus, cementing the pieces, and the land shells contributed their shells to the pile.
4. A time of submergence succeeded, certainly to the amount of 40 feet—some say 200.
5. The land then rose to its present level.

The breccia is fully 25 feet thick, and hence a considerable time was required for its accumulation. At a quarry it is easy to divide the strata into three parts, in the upper two of which the shells are found. The locality was first described by Professor A. B. Lyons.† In a recent letter he says:

> "It seems certain that the shells lived on the mountain and were not brought down in streams from a distance. The vegetation must have been more abundant than now, because the shells are such as are now found in moist localities. As to the species, at least five genera are represented, all such as have their representatives in the valleys of Oahu, though some of the species may be extinct. The genera included *Lepachatina*, three species; *Helicona*, one; *Pitys*, one; *Succinea*, one (like one now living on the head); *Pupa*, I think one, and the old *Helix lamblata*. We should not look for any great antiquity in secondary formations from materials of one of the tufa cones of Oahu. The absence of marine shells from the mass is significant. Submergence must have taken place later."

Specimens from the middle and upper part of the talus-breccia were submitted to Doctor J. T. Gulick, with the query whether any alterations had been made in the later growths, having in mind evolutionary changes. He said that the upper ones vary from those below by being somewhat pinched, as if the surroundings had been less favorable to their existence. The Lepachtiniæ do not require trees for their dwellings, being the terrestrial group of the genus.

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* Lavas and soils of the Hawaiian islands, Honolulu, 1898. See also A. B. Lyons: Chemical composition of Hawaiian soils and of the rocks from which they have been derived. Am. Jour. Sci., December, 1896.

† Thrum's Annual for 1891, p. 103.

Professor Lyons found similar shells on Punchbowl and writes as follows concerning another locality:

> "The most interesting find of fossil shells was in a volcanic tufa (primary) near Pearl Harbor. Evidently the volcanic ash had been deposited in water, the shells brought down in streams, possibly in freshets, and the material, which seems to have had properties like those of Portland cement, set under water to form rock. In a similar material there are preserved many impressions of leaves, apparently like those of the existing forests."

In the Annual, after remarking that one of these species still lives in the Waianae mountains, Professor Lyons concludes that—

> "The fossils belong to a period previous to that of the receding of the ocean to its present level. That event may have been coetaneous with the change of level in the circumpolar area which marked the close of the great Glacial period, and the evidences that our climate was, previously to that time, more humid than at present are confirmatory of that view."

Now that the Diamond Head breccia proves to be of Tertiary age, additional interest will be given to the study of the development of these land shells.

Order of Events in the geological History of Oahu

From the descriptions now presented it is possible to make out the order of the principal events in the geological history of this volcanic island. We are now satisfied with the existence of Tertiary deposits antedating the rise of the earliest basaltic land, but will not consider whether there may have been any rising of the ocean floor in connection with the eruptions.

1. At the base of Kaala igneous eruptions commenced under water to accumulate sheets of basalt until finally the island of Kaala, a smooth dome, rose above the waters, which slowly became covered by vegetation derived from distant regions.
2. This dome became extensively channeled by streams produced as now by the condensation of the moisture brought by the northeast trade winds. Like existing islands under the same conditions, the erosion was greater on the northeastern than southwestern sides.
3. The island of Koolau came up quite near to Kaala in a similar manner, and lava flowed down so as to conceal several hundred feet altitude of the northeast flank of Kaala. Koolau extended out to sea several miles farther to the northeast than at present.

4. Coralline and molluscan limestones commenced to grow as soon as the reef-building animals could migrate hither. Doubtless the work commenced in the first period, and has continued ever since, coeval with the other phases of growth. If we were to judge of age from the amount of work accomplished we should say the earlier stages of growth corresponded to the work done elsewhere in the later Tertiary. The slow upbuilding of the volcanic domes and their subsequent erosion required an immensely long period for their accomplishment. The island was also a thousand feet higher than at present, if the Darwinian theory of the origin of coral reefs is true.

5. Eruption of the amygdaloidal basalt at the Pali.

6. The chrysolitic basalt formed laccolites at the Pali. Some of the dikes, both in the Kaala and Koolau areas, may have filled fissures at this time.

7. Eruption of an igneous agglomerate containing pebbles of chrysolite; may have produced craters in both areas; described typically at the Pali.

8. Quite widely extended ejection of red ash, clinker, and lava at the Pali, and the formation of Makakilo and Kupuai of the Laeloa craters; some of the Tantalus series of craters.

9. Ejection of some of the basalts penetrated in sinking artesian wells.

10. Tuff craters, probably not all active at the same time—the Salt Lake group, Punchbowl, Diamond head, the Koko heads, Kaneohe group, etcetera. The tuffs came up through coral reefs, the land probably being lower than at present; vegetation as flourishing as at present. Five substages indicated along Oahu Railway and Land Company near Moanalua station.

11. Decay of the surface of the tuff and, of course, of all the other rocks, so as to produce soils.

12. Discharge of ashes from Tantalus, Punchbowl, Diamond head, Koko head, and elsewhere, followed by showers of stones.

13. Numerous eruptions of basalt and formation of most of the Laeloa craters—Kuua, Palailai, Kapuai, Kamuki, Mauumae, Rocky hill.

14. Dikes cutting Punchbowl, Diamond head and coral reef, Kaena point, Kupikipikio, and Koko head.

15. Time of the accumulation of calcareous talus-breccia with Achatinellidæ at Diamond head.

16. Depression. Over the Achatinella beds is a red marine earth abounding in transported coral, shells, fish remains, etcetera, reaching to 40 feet above the sea. At the altitude of 200 feet on the east side of Diamond head, I found corals loose on the surface, more readily referable to the former presence of the ocean than to their removal from the

tuff by rain. Professor Lyons writes that he has observed terraces, apparently of marine origin, on the coast side of the Pali 100 feet above tidewater. Brigham and Dutton in their writings agree as to the existence of a depression of the land somewhere about 200 feet at this epoch. Some one asks, Could not the elevation of these organisms have been effected by an earthquake wave?

17. Elevation to the present level. Accumulation of dunes.

Notes on the Tertiary Geology of Oahu* by W. H. Dall

During a visit to Honolulu in August and September, 1899, I examined with much interest the scanty fossiliferous strata which exist in that vicinity.

Near the eastern extreme of the island are quarries of calcareous rock from which road metal is obtained. These beds contain stratified layers partly of more or less consolidated coral sand interstratified with brecciated tuffaceous material, apparently deposited in water, the interstices filled with fine marl containing small species of Helicina and Achatinellidæ of the small terrestrial types, such as Amastra and Auriculella. Here and there were small lenticular masses of fine blackish sand with many granules of olivine.

Ascending to a more or less denuded surface largely corresponding to a layer of volcanic rock which forms the natural surface of the ground above the quarries, here and there patches of calcareous rock remained in depressions in the lava, containing thoroughly fossilized marine shells of many genera, of which the most conspicuous were the solid shells of Conus and Purpura, tropical types of the Indo-Pacific fauna, but, so far as my observation went, not at present represented on the adjacent beaches. This horizon corresponds to that of the basal limestones of Diamond head, farther east.

Diamond head, the conspicuous hill at the southeastern extreme of the island, is isolated and considerably denuded, but exhibits numerous good sections, especially on the seaward face near its base. It is composed of horizontal layers of tuff, interstratified with thin layers of calcareous sand, the lime from which, leached out by the rain, is redeposited in a thin superficial crust of a brilliant white, giving the effect, among the sparse arid vegetation, of a thin layer of snow. The strata of the Head have not the "onion peel" aspect of layers of successive subaerial eruptions, but are strictly horizontal and have every aspect of having been deposited in water. Occasional somewhat thicker layers of sand show "wave structure" in their fluctuated lines.

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* Printed by permission of the Director of the U. S. Geological Survey.

The amount of volcanic material in proportion to the lime rock is much greater as one ascends. My observation was not carried to a point more than 100 feet above the sealevel, but it is evident that the sand layers occur, interstratified in the mass, clear to the top (700 feet). The upper limy layers appear, so far as observed, to be composed almost entirely of calcareous sand, and no shells or corals were observed in them in a recognizable state. At about 50 feet above the sea the heavy tuffs overlie the uppermost heavy layers of calcareous rock. The latter is nearly or quite horizontal, and consists of coral sand grains more or less compactly consolidated, with occasional patches where marine fossil shells were abundant. There are hardly traces of coral larger than fine gravel and no coral masses. Where exposed the limestone has been more or less subjected to solution by rain, and is usually covered by a crust of the character previously mentioned, generally about an inch thick. Below the upper and more sandy layers the rock is harder and the sand grains smaller; but the shells are more numerous and weather out in a very perfect condition. They are mostly gastropods. Still lower, casts and impressions of Ostrea and Avicula and coral heads less than a foot in diameter are present. The bottom of these limestone rocks is below the present sealevel. I saw nothing which could be regarded as an elevated reef of coral, but the rock presented the closest analogy to what is usually designated "beach rock" in coral regions. The conclusion to which I came was that the whole mass of Diamond head had been slowly deposited in comparatively shallow water and gradually elevated without being subjected to notable flexure. The ejection of material at first must have been intermittent, with long quiescent periods, to enable the shore to have been repopulated with mollusks and corals. The later layers may have been more frequently ejected, as indicated by the absence of perfect fossils or of any fossils, by the thinner calcareous and the heavier tuffaceous layers.

The conditions appear to be incompatible with the reference of the fossiliferous beds to a period as late as the Pleistocene. It is difficult to make an exact comparison from the paleontological data, as the recent fauna is still imperfectly known, and we have no standard of comparison in the whole Polynesian region by which the species could be compared with those of Tertiary beds of known age; but the fossils have every characteristic of those generally assigned to the Pliocene or upper Miocene in their general aspect and state of fossilization.

It is an interesting fact that the Achatinellidæ have been recently determined by Professor Pilsbry, of Philadelphia, from their anatomical characters, to belong to a very primitive type of Pulmonata, analogous to Limnæa, rather than the Bulimulus group, with which they have been long associated on solely conchological grounds. It is not insignificant, either, that the fossil forms of this group found at the quarries are of the small, ground-loving species which might be transported with comparative ease by storms or other agencies, and not the large arboreal species which may be supposed to be a more modern development on the spot, being exclusively confined to these islands, while Auriculella, Tornatellina, etcetera, the smaller types referred to, are much more widely distributed. There can be little doubt from their remarkable development that the Achatinellidæ reached these islands in Tertiary times, and that their present luxuriance of form and color is the product of a prolonged period of local evolution.

In the opposite direction from Diamond head, on the shores of Pearl harbor, a very similar series of beds to those at the base of Diamond head were exposed. The usually perpendicular face of the rock fronting the beaches usually rises about 30 feet above tide, but is largely reef rock with shells and corals in abundance, well consolidated and with several feet of alluvium above it. The strata are gently undulated, but in no special or uniform general direction. About midway of the bluff a layer of lava about 8 to 10 inches thick was noted, which had apparently flowed over the reef rock below it, and above which another series of reef rock beds like the lower ones had formed. Ostrea, Monodonta, Tellina, Avicula, etcetera, were noted in the reef rock, from which many of the shells had been removed by solution. It should be noted that the reef rock which underlies the western part of the city of Honolulu and crops out at the water line in Honolulu harbor appears to be of an extremely similar if not identical character.

In the alluvium around Pearl harbor quantities of kitchen-midden material was observed, chiefly Avicula and *Ostrea sandwichensis*, now found living abundantly in the adjacent waters.

About a quarter of a mile eastward from Waipio station on the Oahu railway between Pearl harbor and Honolulu is a cut through a ridge of earth, marl, and clay rising about 20 feet above the track and 35 feet above tide. The beds dip seaward at a moderate angle. The section is as follows:

Red lava earth	3	feet.
Marl with wave structure	8	"
Clay layer with extinct oyster	1	"
Clay	2½	"
Marl	1	"
Clay	4	"
Total above base	19½	"

Near the middle of the section is a bed of oysters, fossilized where they grew and belonging to a species not represented in the recent fauna of the islands or in the kitchen-middens. The beds of which the above section is composed are newer than and situated above the coral-reef rock, which for the purposes of designation may be termed the Pearl Harbor formation. No mollusks or other fossils except the oyster and a few fragments of barnacles were found in this locality. The limy clay or marl above the layer with oysters showed unmistakable evidence of wave action in its structure, while the decomposed lava earth above was evidently an alluvial deposit.

To sum up, it is concluded that the reef rock of Pearl Harbor and Diamond Head limestones are of late Tertiary age, which may correspond to the Pliocene of west American shores, or even be somewhat earlier, and in the localities studied there was no evidence of any Pleistocene elevated reefs whatever. It is probable that Oahu was land, inhabited by animals, as early as the Eocene.

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THE TETRAHEDRAL EARTH AND ZONE OF THE INTERCONTINENTAL SEAS

ANNUAL ADDRESS BY THE PRESIDENT, BENJAMIN KENDALL EMERSON

(Read before the Society December 27, 1899)

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"And after this I saw four angels standing on the four corners of the earth, holding the four winds of the earth." Rev. 7:1.

A Prelude on Influence of Vulcanism of the Mediterranean Zone on Thought

Whether Empedocles, the proud philosopher of Agrigentum, leaving his brazen sandals on the crest of the mountain, cast himself into the crater of Etna, despairing of any solution of the problem of the universe, or whether, as the first of a long line of scientific martyrs, he fell a victim to his zeal for knowledge while searching at the fountain-head to know of the pyriphlegethon—that *μεσον πυρ* or *πυρ εν κεντρω*, that central fire of his master, Pythagoras—we may be sure that the volcanic fires of the Mediterranean illuminated the esoteric doctrine of the schools at the very dawn of Greek philosophy. The imagery of religious exaltation has from the beginning borrowed its grandest symbolism from the volcano and the earthquake. We have wandered with Æneas through Avernus in the solfataras of the Phlægrean fields, have recalled Vulcan as we sailed past Etna, and the goddess Pele beside the caldron of Kilauea. In the presence of the peerless cone of Fuji-san, we could not wonder at the Via Sacra, along which the pious pilgrims, ascending, worshipped the holy mountain.

The Persian account of the flood adds a volcano to the earthquake of the Gilgamos Epos:

> "Out of the south arose a great fiery dragon. Day changed to night. The stars disappeared. The zodiac was covered by the great tail. Only sun and moon could be seen in the heaven. Boiling water fell and scorched the trees to their roots. Amidst constant lightning fell drops of rain as big as one's head. After ninety days and ninety nights, the enemy of the earth was destroyed."*

Saint John † the Divine, in his Apocalypse, said: "I, John, who also am your brother and companion in tribulation, . . . was in the isle that is called Patmos, for the word of God." This was probably in the year 60, and Doctor Dekigallas, in his history of the eruptions of Santorin, the great submerged crater which rises from the sea like one of the lunar mountains, in plain view of Patmos, tells us, on the authority of George of Syngelos, that in an eruption of Santorin which occurred in this year "Palaia Kaumeni," the *insula caustica antiqua*, was increased by the emergence from the sea of a great volume of lava, which formed a cape stretching toward Patmos. Now Santorin is Saint Irene, but the

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* Mayer: Die Entstehung der Erde, p. 383.

† Theodore Bent: What John saw in Patmos. Nineteenth Century, vol. XXIV, p. 817.

Greek name was Thera—that is, "the beast" (θήρ, θήρα), the Theia of Pliny. And Saint John said: "I stood upon the sand of the sea and saw a beast"—that is, Thera (θηρίον)—" rise out of the sea, having seven heads and ten horns." Later he interprets: "The seven heads are seven mountains." And as he was long after looking at the island rising silent in the sea, he closes his account with the strange sentence:

> "They that dwell on the earth shall wonder when they behold the beast that was and is not, and yet is."

I quote the following verses as but a sample of the seismic imagery which is continued consistently through the whole Revelation.

> "And I beheld when he had opened the sixth seal, and lo, there was a great earthquake, and the sun became black as sackcloth of hair, and the moon became as blood; and the stars of heaven fell upon the earth, even as a fig tree casteth her untimely figs. And the kings of the earth, and the great men, and every bondman, and every freeman, hid themselves in the dens and in the rocks of the mountains.
>
> "And the second angel sounded, and as it were a great mountain burning with fire was cast into the sea; and the third part of the sea became blood; and the third part of the creatures which were in the sea, and had life, died; and the third part of the ships were destroyed. And the third angel sounded, and there fell a great star from heaven, burning as it were a lamp, and it fell upon the third part of the rivers, and upon the fountains of waters; and the name of the star is called Wormwood; and the third part of the waters became wormwood, and many men died of the waters, because they were made bitter.
>
> "And the fifth angel sounded, and I saw a star fall from heaven into the earth, and to him was given the key to the bottomless pit. And he opened the bottomless pit; and there arose a smoke out of the pit, as the smoke of a great furnace; and the sun and the air were darkened by reason of the smoke of the pit. And the second angel poured out his vial upon the sea; and it became as the blood of a dead man; and every living soul died in the sea. And there were voices and thunders and lightnings; and there was a great earthquake, such as was not since upon the earth, so mighty an earthquake and so great. And every island fled away and the mountains were not found. And there fell upon men a great hail out of heaven, every stone about the weight of a talent; and men blasphemed God because of the plague of hail; for the plague thereof was exceeding great. And every shipmaster, and all the company in ships, and sailors, and as many as trade by sea, stood afar off, and cried when they saw the smoke of her burning, saying, What city is like unto this great city? And they cast dust on their heads, and cried, weeping and wailing, saying, alas! alas! that great city, wherein were made rich all that had ships in the sea by reason of her costliness! for in one hour she is made desolate."

Here is given in terrible concentration the story of Tomboro or Krakatoa. Indeed, using modern language, I could parallel the recital from the accounts I have studied of eye witnesses of the many eruptions of Santorin itself. Strong submarine explosions have blown water and volcanic ashes mingled with fire from the submerged caldera, and the iron dissolved out of the lava, as described by Father Richard three centuries ago, has made the water red as blood as far as the eye could see, and great bombs, many cubic meters in size, as Fouqué reports, have fallen like the star called Wormwood. Ships were shattered and sailors and landsmen stifled in the noxious vapors. Sailors floated to sea dead in their boats, and the survivors were blinded and suffered serious diseases and fled away and hid themselves in the caves dug in the tuff beds up the mountain side. Islands have risen from the sea or grown under the eye of modern students. Other islands have disappeared, like Colombo. Von Seebach, my teacher at Göttingen, fresh from the study when I worked with him, told me many things of the volcano. Red hot bombs crashed through the decks of a Prussian frigate, endangering her magazines. One sails by a narrow passage into this submerged caldera, and the black crater walls are livid from the red and yellow stains of sulphurous exhalations.

The surging outrush of the sulphurous vapors mingled in the night with the glare of fiery lava masses formed the lake of fire and brimstone into which the angel with the key cast Satan for a thousand years, and distant rumblings underneath the quiet waters of the harbor still tell the simple seamen of the groans of the condemned.

We may regret that we are now no more capable of producing an apocalypse than of composing an epic. We may regret that we can not reach the volcanic intensity of speech and thought when the will to believe required no stimulus and eloquent 'and holy priests consigned the swarming spirits of evil to sulphurous fires in splendid exorcisms, like this from the Flagellum Daemonis of the Reverend Father Hieronymus Mengus Vitellianensis:

> "By the Apocalypse of Jesus Christ which God hath given to make known unto his servants those things which are shortly to take place, and hath signified, sending his angel, I exorcise you, ye angels of untold perversity. And by all the wondrous signs, terrible voices, mighty thunders and mystic visions which Saint John beheld, I exorcise you, O angels who entice unto evil deeds, that ye do go far away from this creature. By the door which John saw open in heaven, by the four and twenty thrones and the four and twenty elders and by the lightnings and voices and thunders which proceeded out of the throne, by the sea which he saw as it were of glass mingled with fire, by the four living beings full of eyes before and behind, by the Lamb as it were slain, by the harps and the vial of gold full of perfume, I charge you, O angels of death, to flee quickly out of this creature."

Volcanic soils produce the richest and strongest wines. They promote, we have seen, most eloquent theological imagery, and have been, we shall see, fertile in a tropical luxuriance of geological imaginings.

A great line of fire, starting with the early homes of culture in the Mediterranean, belts the earth, and, branching grandly in the East and West Indies, cordons the Pacific like the line of signal fires that flashed the tidings of the fall of Troy across the Ægean to Agamemnon in Mycenae.

It is the relation of this fire-bordered zone of intercontinental seas to the triangular continents which it bisects that I desire to consider this evening.

PART I. THE TETRAHEDRAL EARTH

IN GENERAL

While fresh from the volcanoes of Italy, Japan, and the Sandwich islands, I met in Honolulu the friends and relatives of that fine English merchant and original thinker, William Lothian Green. I procured a copy of his rare work, "Vestiges of the Molten Globe,"* thought out on this distant volcano, apart from large libraries and scientific associates. After reading and re-reading the book during the long voyage across the Pacific, the theory of the tendency of the globe to assume in some degree the tetrahedral shape has had great attraction for me. The hypothesis, while mentioned by Dana, who met the author in the Sandwich islands, has received little favor except in France, where de Lapparent and Michel-Lévy have long advocated it. Recently it was made the subject of a lecture before the Royal Geographical Society by Doctor J. W. Gregory.†

GREEN'S HYPOTHESIS OF THE TETRAHEDRAL EARTH

General statement of the hypothesis.—Attracted by the old Baconian problem of the three triangular continents projecting south, the three triangular oceans projecting north, the Arctic sea and the Antarctic land, Green chose the apparently unpromising tetrahedron as the form toward which the earth has imperfectly tended.

The hypothesis considers the earth to possess a somewhat rigid crust resting on a liquid interior which is shrinking from loss of heat. The law of least action demands that this crust shall keep in contact with the lessening interior with the least possible readjustment of its surface. The sphere, of all solids, contains the greatest volume under a given surface, the tetrahedron the least volume under the same surface. The solid spherical crust of the earth, then, collapsing upon its plastic interior, would tend toward the tetrahedral form as the one which would coordinate the greatest diminution of the interior with the least change of the surface. There is a long series of tetrahedroid forms between the tetrahedron and the sphere, and the six-faced tetrahedron with rounded faces—the form so common in the diamond—may nearly approach the sphere, and may be supposed to be the form toward which the earth at first tends (figures 1–3).

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*Vestiges of the Molten Globe, as exhibited in the figure of the earth's volcanic action and physiography, by William Lathan Green, Minister of Foreign Affairs to the King of the Sandwich Islands. Part I, London, 1875; part II, Honolulu, 1887.

†The Plan of the Earth, and its Causes: The Geographical Journal, vol. xiii, 1899, p. 225. Abstract in Nature, vol. lix, p. 350.

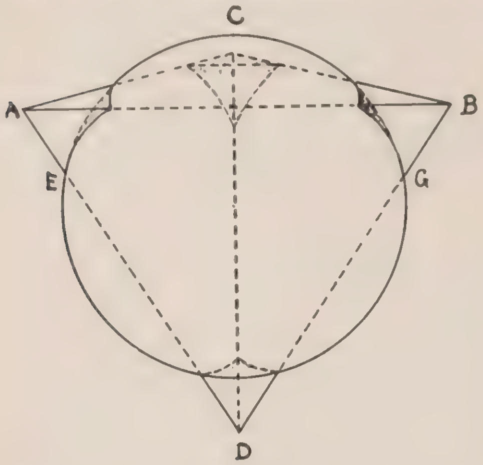

Figure 1.—*Tetrahedron placed symmetrically within a Sphere.*

Showing crudely the ideal relation of the four projecting continents. From Green.

Four low, equal, and equidistant protuberances (A, B, C, D in figure 1; A, B, D visible in figures 2 and 3) of rounded triangular boundaries rise equidistant on the surface of the model. Opposite each is a corresponding broad depression (C and E, visible in figures 2 and 3). If the body be supposed to be placed like a top on one of these protuberances, the other three would make the top three-shouldered, as they would be placed 120 degrees from each other. If the top be revolved, it would be an over-regular model of the rotating earth. The three equidistant shoulders of the top would be the three continents, Eur-Africa, Asia-Australia, and the Americas, triangular

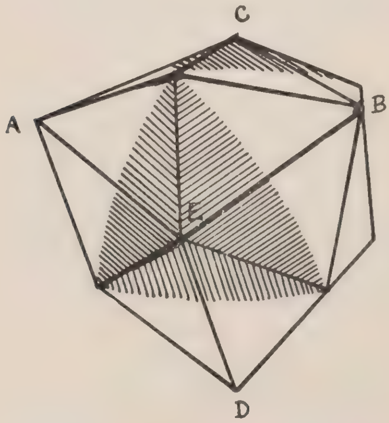

Figure 2.—*Six-faced Tetrahedron (Hexatetrahedron).*

Showing the next approximation toward the sphere, with the depressions representing oceans shaded on the assumption that land and water are equal.

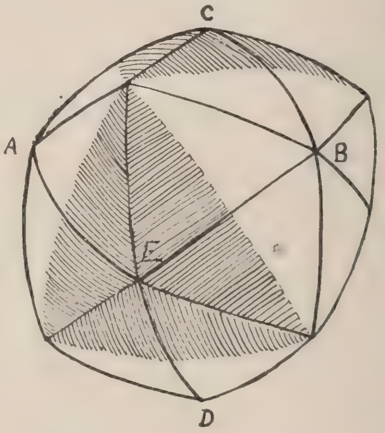

Figure 3.—*Six-faced Tetrahedron with rounded Faces.*

The shading represents oceans equal to the lands.

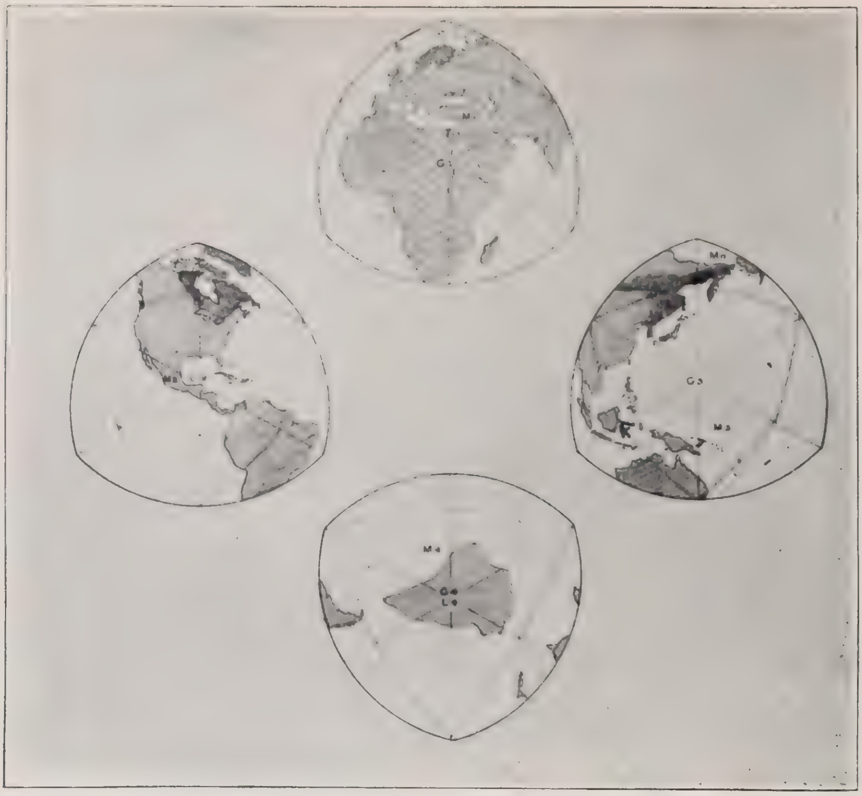

Figure 1.—Four Maps, each containing one-fourth of the Earth, to lessen Distortion

Inner spherical triangles in pencil lines represent position of ideal continents on assumption of perfect symmetry and equality of land and water surfaces. (Green.) Archean shields or protaxes shaded, and adjacent ancient unfolded tablelands and corresponding Archean-Paleozoic unfolded tablelands in southern hemsphere lined.

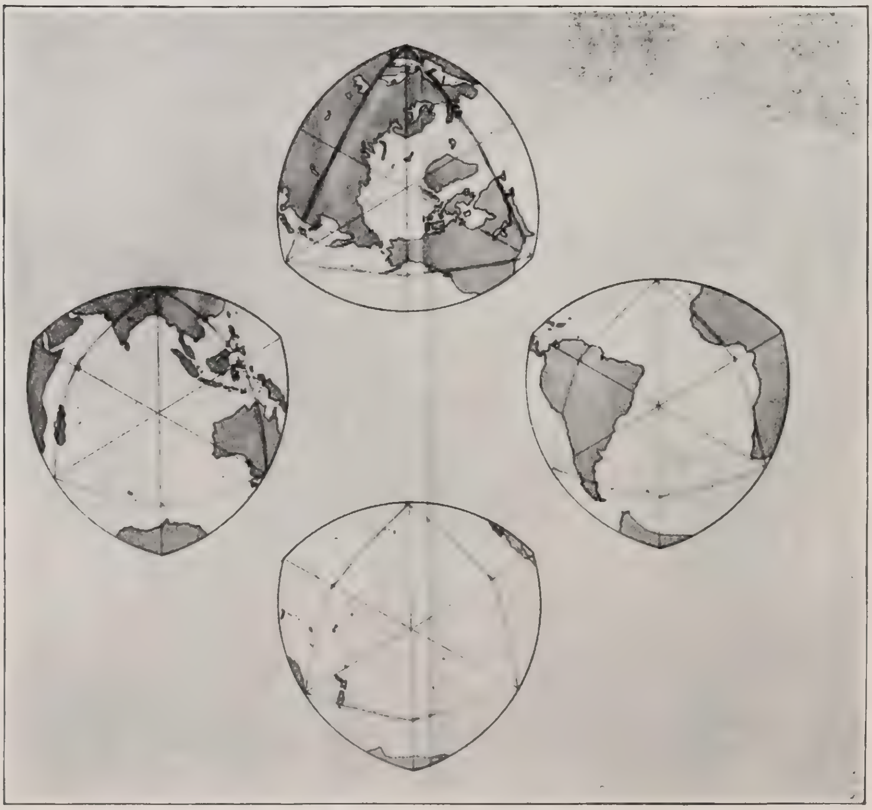

Figure 2.—Four Maps, each containing one-fourth of the Earth, to avoid Distortion

Inner triangles show positions of ideal oceans assuming land and water equal. (Green.)

FOUR MAPS ILLUSTRATIVE OF TETRAHEDRAL EARTH southward and massed around the north pole. Between would be the three oceanic depressions gathered around the south pole, contracting northward. At the ends of the axis of rotation would be the Antarctic continent, the fourth protuberance below, and the Arctic ocean, the fourth depression above (see plate 9, figures 1 and 2).

Shifting of the southern hemispheres.—Because the great masses in the northern hemisphere were raised above their normal level, they would lag to westward; because the great masses of the southern hemisphere were depressed below the normal level, they would be accelerated eastwardly. This explained the position of South America east of North America and Australia east of Asia. Indeed, in his view, the great mass of Asia caused it to lag behind so much that it was thrust against and joined with Europe.

The twinning plane.—These opposing forces produced a shearing of the northern hemisphere on the southern, along a plane passing through the three intercontinental seas, a plane placed 12 degrees nearer the north pole because of the excess of the northern masses, and in the plane of the ecliptic instead of the equator, because the shearing force, although acting in the plane of the equator, found in the ecliptic a plane of weakness caused by the strain of the internal tides. This plane passing through—indeed causing—the three mediterranean seas he called, somewhat fancifully, the twinning plane, and conceived the southern hemisphere to have been rotated about 30 degrees to the right like a twin crystal to bring the southern continents into their present positions.

Without accepting them, I have discussed his explanations of these two points below (see pages 75–78) in order to consider the value of the inertia force and the tidal stresses which he employs in this portion of his hypothesis.

ARGUMENT IN FAVOR OF TETRAHEDROID TENDENCY IN FORMATION OF EARTH'S CRUST

In advancing arguments for his theory, Green cites experiments where hollow tubes uniformly collapse under atmospheric pressure into three-sided forms with rounded edges and concave sides, like a horizontal section of the earth in the southern hemisphere, and claims to have seen a distinctly tetrahedral shape in soap bubbles and bubbles in water, and he cites many cases where astronomers have observed a four-shouldered form in the larger planets.

The hypothesis connects the main facts relating to the earth's grand feature lines by a very simple principle. It would postulate a certain evolution of the continents and oceans, and may, indeed, be taken as furnishing an *a priori* ground for this postulate. It is a hypothesis of the arching of the continents by tangential pressure in accord with the law of least action.

In most cases we find land at one extremity of any diameter opposed by water at the other—a peculiarly tetrahedroid arrangement. This is neatly illustrated by the figure below where the antipodal land is superimposed on a common map of the earth.

Again, all deforming agencies depending on rotation are at a minimum at the poles and a maximum at the equator. The tetrahedroid peculiarities would then be best preserved in the polar regions. Thus we find the polar ocean with a depth of two and a half miles, as determined by Nansen, and bordered by broad lowlands sloping gradually beneath the waters around most of its extent, with two oceans extending southward at two corners, and at the third a deep depression—the Aralo-Caspian area, partly below sealevel and an ocean in reality in the Tertiary—connecting with the Indian ocean.

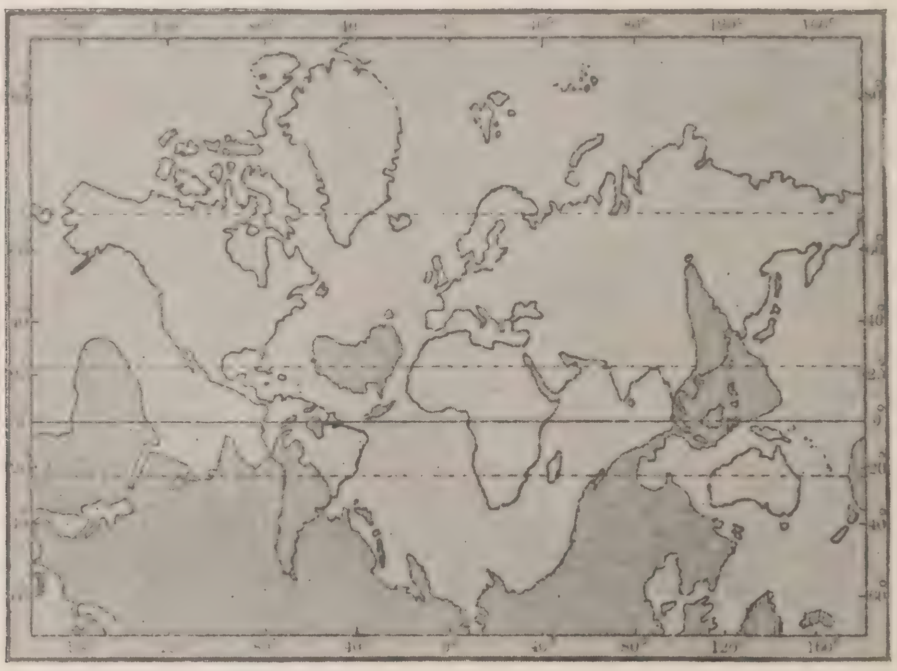

FIGURE 4.—*Map of the Earth.*

Showing that, with the exception of the apex of South America, land and water are symmetrically antipodal to each other. From Gregory.

In the south we find the three-lobed Antarctic continent and the southward triangular prolongations of the other three elevations more nearly equidistant than the corresponding central portions and with the three broad oceans narrowing northwardly between them. A small elevation of the drift covered bank on which Iceland stands would complete the apex of the Atlantic. The southward transfer of the ocean waters has diminished the Arctic sea and the Antarctic land in exact proportion. The mathematical centers of the four oceans are equidistant from each other, symmetrical with the four depressed centers of the model. I have been interested to see the similarity between the land masses as a whole and the ocean areas as given by Gilbert* in his suggestive "orange-peel projection." This is drawn at the true continental borders, making the elevated and depressed areas about equal, as they should be for comparison.

We may now examine in order the series of paleographical maps (plates 10 and 11), very hypothetical, of course, the first five taken mainly from de Lapparent, the last three from Koken,† and see what traces of the tetrahedroid condition appear in the past.

In the first map, taken from de Lapparent,‡ which shows (plate 10, *a*) the present Archean areas on the globe, if we omit the areas which have been brought up from great depths by folding, the remainders arrange themselves in three groups which occupy closely the position of nuclei of the three tetrahedral continents. I have drawn lines on the map 120 degrees apart to show their symmetrical positions. One may compare with this Green's maps, given as figure 1 on plate 9.

At the northern apices of these hypothetical continents are, first, the Canadian shield of Suess or protaxis of Dana, with the shallow water-cover of Hudson bay; second, the Scandinavian shield of Suess, or boss, as Adams has proposed to call these ancient lands. It is partly covered by the shallow Baltic sea. Third is the Manchurian shield of Gregory, or coign, as he would call it, partly covered by the shallow Okotsch sea. Nearly south of each is the southern apex of these embryo continents—the Archean nucleus of Australia, the highlands of Guyana, and the African Archean tableland. Finally, the Antarctic continent is probably Archean, as the boulders from its icebergs show.

If we consider the great mass of the sedimentary strata which has been derived by erosion from these old lands which were folded and worn down in pre-Cambrian times, the fact that they still rise high above sea-level suggests some such constantly working force of upheaval acting upon them as the tetrahedral hypothesis demands. These are the primeval, immovable corner stones of the earth, against which the waves of ancient seas have broken, while they have remained, in part, perhaps, always unsubmerged, and against which mountain ridges have been pressed and broken down like waves of the sea.

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* G. K. Gilbert: Continental problems. Bull. Geol. Soc. Am., vol. 5, p. 185.

† E. Koken: Die Vorwelt, 1893, p. 1.

‡ Traité de Géologie, 1900, p. 739.

The second or Silurian map (plate 10, *b*) is too hypothetical to have great value in this connection.

In the third map (plate 10, *c*) the broad Carboniferous land belts the earth in the northern hemisphere, and Gondwana land connects the southern continents, and plate 11, *d* shows a similar state of things in the Trias. These lands are carried in broad bands across the present oceans largely on the evidence of faunal identity or similarity, and the lines could generally be carried in northward and southward loops across the present oceans, as is done in several cases.

"There is not wanting evidence," says Seward,* "in favor of the Glossopteris flora having been first differentiated in an Antarctic continent toward the close of the Carboniferous period."

The last investigations of M Zeiler in South America show that the Glossopteris flora came from the south, and the same indications appear in its other occurrences.†

"I have sometimes speculated," says Darwin, "whether there did not exist somewhere during long ages an extremely isolated continent, perhaps near the south pole."‡

The Jurassic map usually quoted is the map of Neumayr, and it is interesting to compare therewith the much later map (plate 11, *a*) of the same period, just published by de Lapparent, who bases his work avowedly on that of Neumayr. The approximation to the tetrahedral symmetry is much greater than in the older map.

In Jurassic time there is a distinct approach to the form demanded by the hypothesis; in the Cretaceous (plate 11, *b*, *c*) it is much increased, although the map-makers take great, and it may be unwarranted, liberties with the north Atlantic.

In the Eocene (plate 11, *d*) the assumptions of the hypothesis are best met, in one respect better than in the modern map, since the Indian ocean is continued north between India and Africa and east of the Urals to the Arctic, and the Atlantic contracts west of Scandinavia. The Mediterranean water belt still continued, but the Miocene mountain-making, extending from Pyrenees to the Himalayas, raised parts of Arabia and Persia and cut off the northern prolongation of the Indian ocean. There is a certain survival of the continental nuclei and progressive evolution of the oceans.

I call attention again to the reproduction of Green's maps, showing, to diminish distortion, the four quarters of the earth instead of the usual hemispheres, and have drawn in the outlines of the ideal continents

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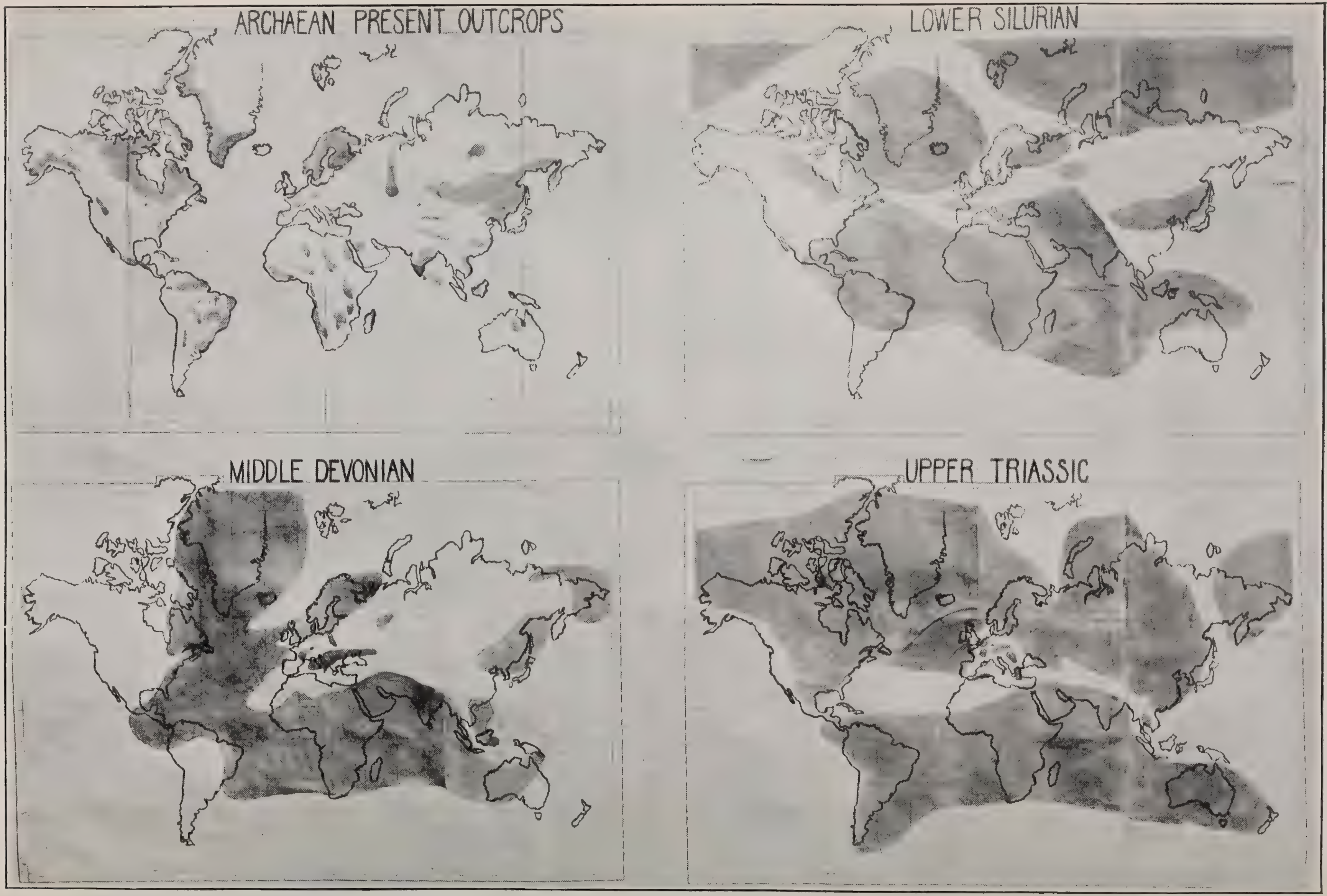
* Association of Sequoia and Glossopteris in South Africa. Quar. Jour Geol. Soc., vol. 53, p. 327.

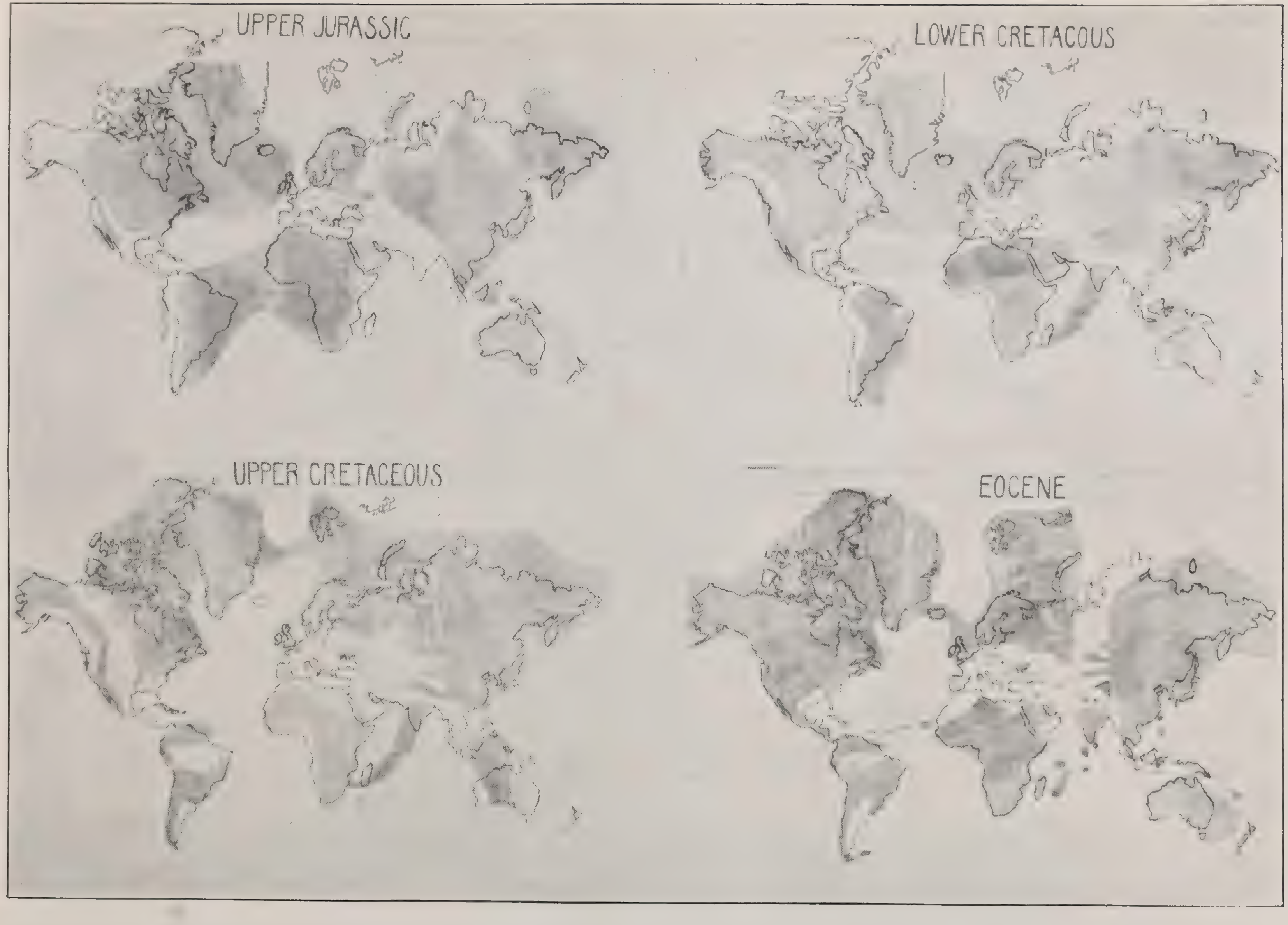
† Bertrand: Bull. Geol. Soc., France, vol. xxiv, 1896, p. 24.

‡ Darwin: Life and Letters.



LAND AND SEA DISTRIBUTION IN THE GEOLOGICAL PERIODS

a, present distribution of Archean outcrops; *b*, distribution of land and sea in Lower Silurian; *c* and *d*, in Middle Devonian and Upper Triassic (de Lapparent)



LAND AND SEA DISTRIBUTION IN THE GEOLOGICAL PERIODS

a, Jurassic, from de Lapparent; *b*, Lower Cretaceous; *c*, Upper Cretaceous, and, *d*, Eocene. From Koken (plate 9, figures 1 and 2, page 67) and shaded the Archean areas and marked in lines the Archean-Paleozoic tablelands. The coincidences and discrepancies are both strongly marked

GEODETIC CONSIDERATIONS

No objection can be raised to the proposed hypothesis from the spheroidal form of the earth, for the earth is not only flattened at the poles but flattened at the equator, and pendulum observations show it is drawn out at the south pole like a top, as our hypothesis would demand, or like a flattened top—like a potato, Professor Darwin has suggested. Herschel said, "The earth is earth-shaped."* It is safe to call it a geoid.

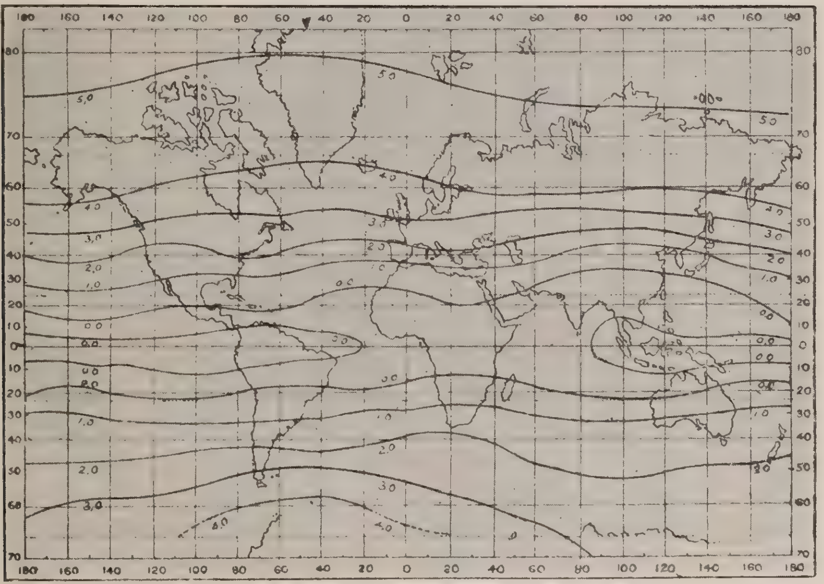


FIGURE 5.—*Map showing Variations in the Attraction of Gravity.*

Numbers 0–5 indicate number of millimeters to be added to the pendulum beating seconds at the equator to make it beat seconds at different latitudes.

It is so irregular that in one of the most refined series of astronomical measurements undertaken by the Königlich-Kaiserliche topographische Militar-Institut zu Wien, the longitude Vienna-Milan and Vienna-Brescia-Milan did not agree, although corrections were made for the quinine taken by the observers when working through marshes.

La Caille in 1751 measured the length of a degree at the south pole and found a curvature differing from that in corresponding latitudes in the northern hemisphere, and his results were confirmed and extended by Maclear.

A pendulum swings more rapidly the nearer it is to the center of the earth, and a pendulum swinging in a second at the equator must be lengthened to beat seconds elsewhere.

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*Gregory, loc. cit. p. 342.

In figure 5 is given Steinhauser's map, showing how many millimeters must be added to the pendulum that beats seconds at the equator to make it beat seconds at other stations north and south.

The pendulum has to be elongated less rapidly southwardly than northwardly, showing that the earth is elongated southwardly. If the piling up of the waters in the southern hemisphere is due to the greater density of the latter, then the top-like elongation is all the greater. Bessel's ellipsoid, calculated in Europe, agrees best with gravity determinations in Europe. Clark's ellipsoid, calculated in Asia, agrees best with facts in Asia. Both may be equally correct. The larger deformation of Asia makes it a segment of a different ellipsoid from that of Europe.

The great deficiency of gravity in the United States, in western Russia, and in India agrees with their greater distance from the earth's center on the tetrahedral continents. The great excess of gravity on oceanic islands agrees with their lesser distance from the earth's center on the tetrahedral oceans; and this meets the approval of Mr E. D. Preston in his report on the study of the earth's figure by means of the pendulum. He says:

> "If we admit the tetrahedral system, these ocean areas are really nearer the center of the earth, and hence should show increased gravity, while the continental masses would tend to increase the effect still further by elevating the surface of the sea in their immediate vicinity. It has been shown that the attraction of the Himalayas would elevate the surface of the ocean immediately under them 1,000 feet. Nothing is more in accordance with the action of physical laws than that the earth is contracting in approximately a tetrahedral form." *

S. O. Listing found the island Marañon sunk 1,858 feet below the normal surface of the spheroid, Saint Helena 2,778 feet, and the Bonin islands 4,294 feet.† M du Ligondés has found that discrepancies between values derived from equations for the density of the earth's interior and from the theory of precession were reconciled by assuming a tetrahedral form for the earth.‡ De Lapparent has suggested that the discrepancy between the geologists who have based their value of the polar flattening 1 : 294 on measurements in the northern hemisphere and astronomers who obtain the value 1 : 297 from the precession of the equinoxes may be reconciled if the southern polar protuberance be admitted.§

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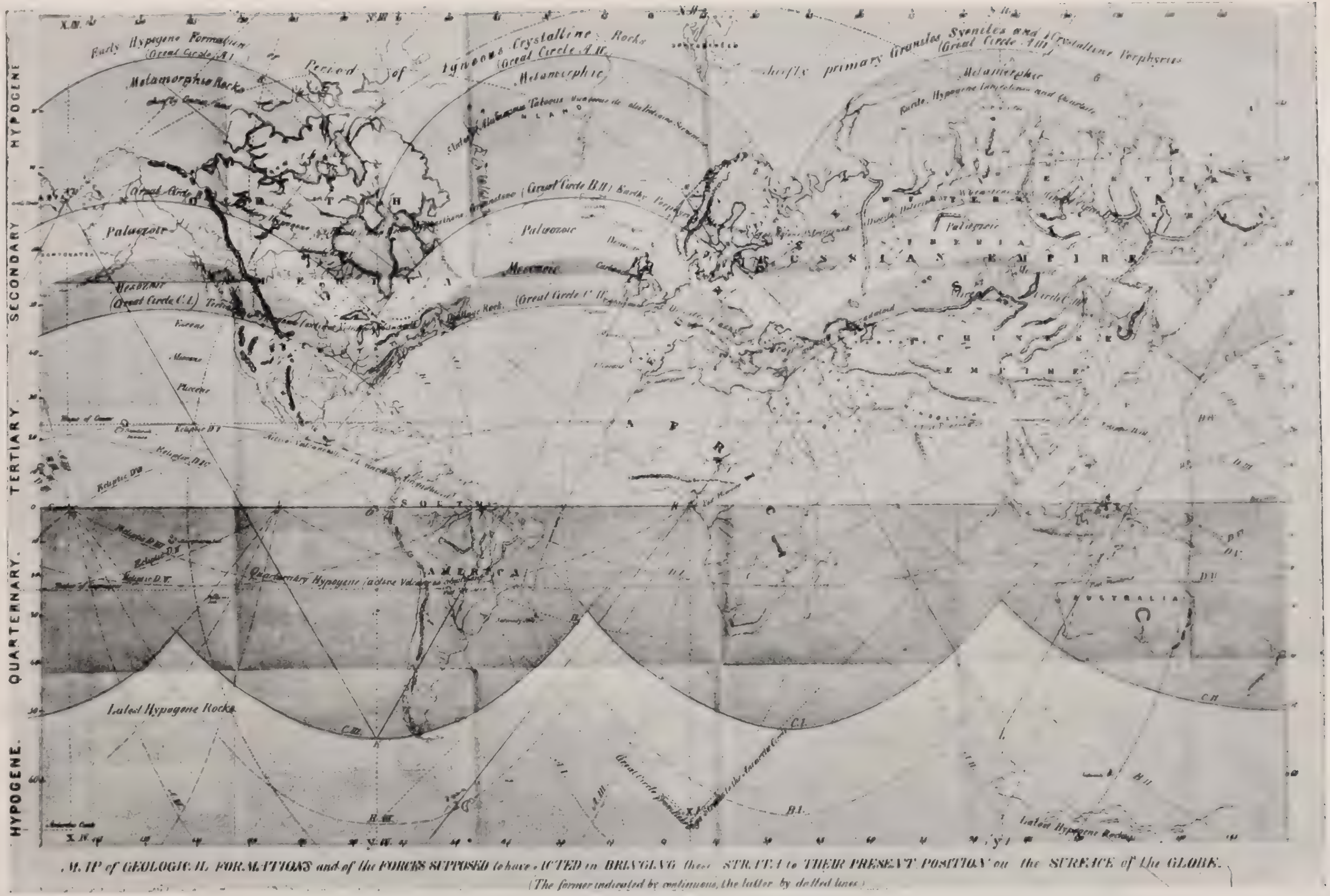
* Am. Jour. Sci., 3d series, vol. xli, 1891, p. 451.

† Nachricht d. k. Akad. zu Gött., 1877, p. 749.

‡ Compte Rendu, January, 1899, p. 160.

§ La Nature. Quoted in Nature, vol. 56, 1897, p. 37.


HYPOGENE
SECONDARY
TERTIARY.
QUARTERNARY.
HYPOGENE.
Early Hypogene Formation (Great Circle A I)
Period of Igneous Crystalline Rocks (Great Circle A II)
chiefly primary Granites Syenites and Crystalline Porphyries (Great Circle A III)
Metamorphic Rocks
Metamorphic
Palaeozoic
Great Circle B II
Mesozoic
(Great Circle C I)
(Great Circle C II)
Eocene
Miocene
Pliocene
Quarternary Hypogene (active Volcanoes)
Latest Hypogene Rocks
RUSSIAN EMPIRE
SIBERIA
CHINESE EMPIRE
AFRICA
SOUTH AMERICA
AUSTRALIA
MAP of GEOLOGICAL FORMATIONS and of the FORCES SUPPOSED to have ACTED in BRINGING these STRATA to THEIR PRESENT POSITION on the SURFACE of the GLOBE.
(The former indicated by continuous, the latter by dotted lines.)

GEOLOGICAL MAP OF THE WORLD

(From Richard Owen's "Key to Geology")

Whether we assume for the earth a nebular or a meteoric origin, the tendency in the cooling globe to tetrahedral deformation of the outer crust may be taken to be a *vera causa*, which, because of the constancy of its action over long periods of time, may produce cumulative results at times and places where its action is permitted by the balancing of other forces, as the rotation of the earth may cause the deflection of a stream to the right under favoring conditions.

The gravity determinations of Putnam, as interpreted by Gilbert, assign to the earth a considerable effective rigidity, one capable of sustaining the greater mountain chains and plateaus of the continents, while indicating for the continental arch a condition of isostatic equilibrium. It would seem that this might imply a rigidity not enough to hold up the continents on the principle of the unsupported arch, but to give such direction to the crumpling that must accompany the readjustment of the crust that it should approach the tetrahedral form rather than the generally disseminated wrinkling of the baked-apple type. As the settling of the depressed areas might cause a lateral transfer of the superficial and thus lighter portions of the subcrust beneath the continental areas, the tendency would be toward such a condition of isostacy that the crust would be almost equally supported in all parts by the highly viscid subcrust. Continued shrinking of the nucleus would cause continued renewal of thrusts that, as epeirogenic forces, would tend to increase the tetrahedral deformation, or, at other times localized as orogenic forces, would add mountain chains like the Appalachian to the continent by an impulse coming from the sea. When collapse of the earth's crust commenced at any point it would lose the advantage of the principle of the arch, and this collapse would spread in all directions until limited by the encroachment of other centers of depression. The tetrahedral form need not be perfectly realized. Like a leaf stung on one edge, so that the side grows unduly small, the one depression may be slightly hindered in time of starting or rapidity of growth. Thus the Pacific may have become over large in comparison with the other oceans.

OTHER TETRAHEDRAL MAPS

Map of Richard Owen.—As a document containing the first suggestion of several of the points of the tetrahedral hypothesis, we present here the quaint and interesting map of Richard Owen (plate 12), whose peculiar book suggests the Naturphilosophie of Oken in its extension of geology by strange and forced analogies into every department of human knowledge. He has, however, accurately mapped the three protaxes

120 degrees apart, and indeed the fourth Antarctic one also, and outlined the development of the North American continent and brought out the greater development of the newer formations southward. He was the first to enumerate extensively the coincidences of the earth's feature lines with great circles.

He suggested that the nucleus of the earth was a tetrahedron or a spherical tetrahedron, and figures in illustration the "nucleiform tetrahedron" and a "crystal of carbon (diamond) being a curved tetrahedron, sometimes almost spherical."*

Map of Michel-Lévy.—The interesting map of Michel-Lévy, cited on page 82, deserves careful study (plate 13). It is constructed strictly in the spirit of Elié de Beaumont. The author starts directly from the assumption that the crust will tend to break along the tetrahedral edges and draws as the three edges meeting at the south pole the Carboniferous Australian Alps, the Tertiary Andes, and the Erythrian rift valley of Africa and Asia Minor, which is not a mountainous region, but near a watershed.

We have been guided rather by the idea that the main geological accidents would occur around the borders of the low rising domes, where the shoreline determines sedimentation, mountain-making, and vulcanism. By placing the tetrahedral pole at Bering strait, he ignores the symmetry of the Arctic ocean and the Antarctic sea, and the symmetrical position of the three Archean coigns.†

But the delightful thing in the whole matter is that he places the tetrahedral pole in Bering strait and leaves the earth pole where it is, and we in the next chapter shift the earth pole to Bering sea and leave the tetrahedral pole where the earth pole now is. He extends the conditions of the western Mediterranean where the southern ranges have moved south, the northern and western north, more widely than Suess has done, and here we have followed Suess.

Doctor Gregory ‡ follows Michel-Lévy closely, but assumes, in addition, that the earth was in pre-Carboniferous times a tetrahedron with apex directed north instead of, as at present, directed south, with Australian, African, and Patagonian Archean nuclei, with the Hercynian and perhaps the Carboniferous chains of Tsinling for the meridional chains,

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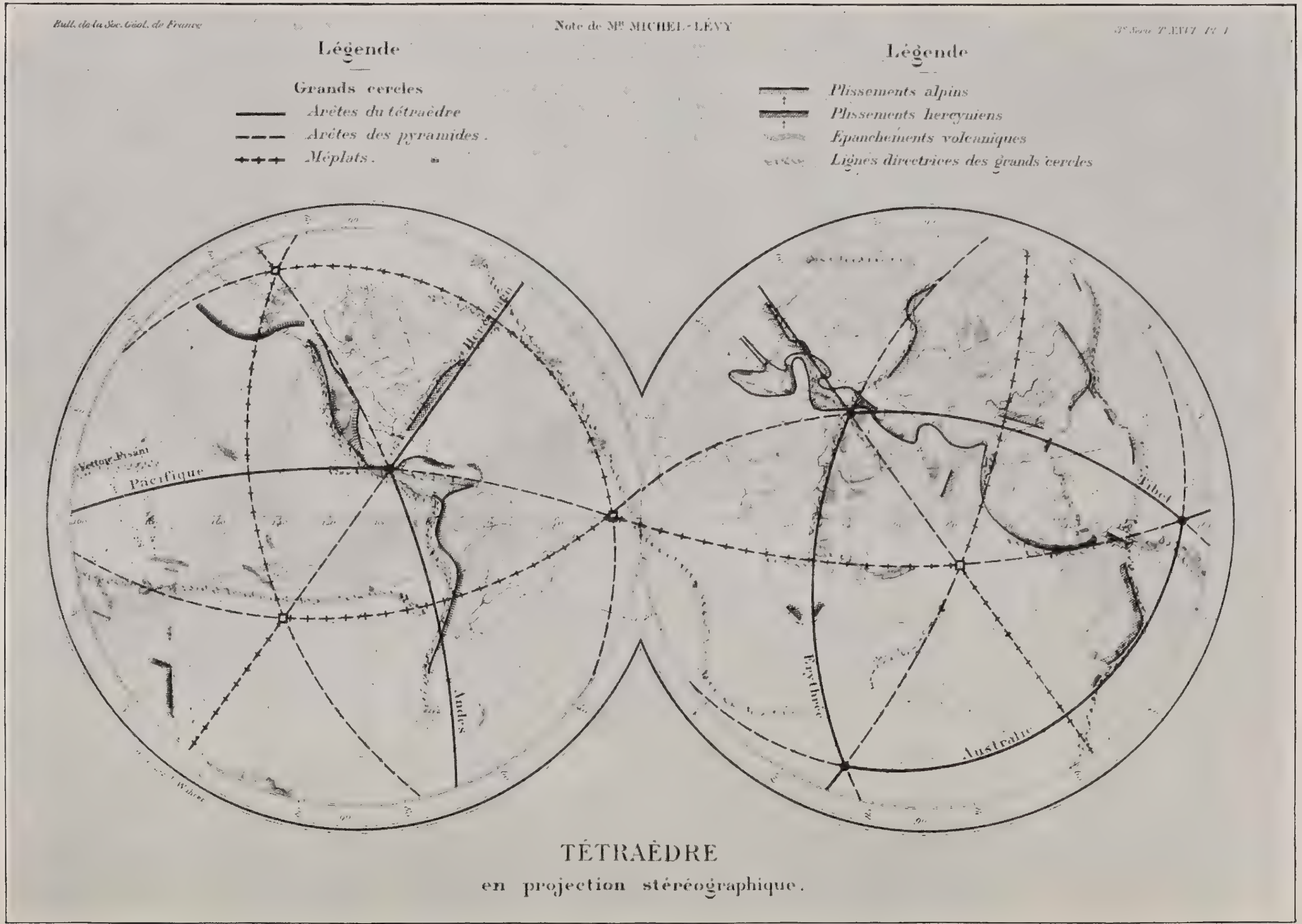
* Key to the Geology of the Globe. An essay designed to show that the present geographical, hydrographical, and geological structures observed on the earth's crust were the result of forces acting according to fixed demonstrable laws analogous to those governing the development of organic bodies. 1857, pp. 23, 60.

† Sur la coordination et la répartition des fractures et des éffondrements de l'écorce terrestre en relation avec les épanchements volcanique. Bull. Géol. Soc. France, vol. xxvi, 1898, p. 105.

‡ Loc. cit.



MAP OF MICHEL LÉVY

Showing tetrahedral arrangement of main feature lines and volcanic areas or earth's surface

and Appalachians, Urals, and Kamchatka corresponding to the three polar edges of the tetrahedron.

SHIFTING OF THE SOUTHERN CONTINENTS

We have, secondly, to consider the apparent eastward shifting of the southern masses, which Dana enumerates among the unsolved problems of geology. While Africa and Europe form a triangular mass agreeing fairly in position and shape with the required tetrahedral continent, South America and Australia are displaced to the east of their expected position south of their northern components.

Green explains this by saying the southern hemisphere mainly sunk below the average level into a circle of lesser radius would move eastwardly in advance of the rest of the earth.

It is, indeed, suggestive that in the northern hemisphere the larger the continent the greater the apparent westward motion from the position required by the hypothesis; in the southern, the smaller the continent the greater the eastward motion, as if in the north the elevated lands had done the work, in the south the depressed seabottom.

Since, however, Africa is scarcely shifted eastwardly in relation to Europe, South America much shifted, and Australia more, no torsion of the whole southern hemisphere can have brought these continents into their present position. This was also recognized by Green, who said the separate oceans, sinking on the west of the continents, would thrust them eastwardly proportionately to the size of the oceans.

Nor can this effect be produced "in the incipient stage of the first formed crust," as Dana interprets Green, for a thick crust of effective rigidity must be formed before elevations and depressions could result of sufficient magnitude to be the cause of torsion between the hemispheres or continental masses.

While rejecting such torsion or moving of the continents, we may yet observe that America and Asia have moved westward in another way, to wit, by the sinking of lands along their eastern border and by the addition of lands along their western border, and Australia has moved eastward in the same manner.

Along New England and north rias coasts abound where mountain ridges strike to the shore, showing that their continuation is to be found sunken beneath the waters.

The eastern lands from which the Appalachians derived their sediments are submerged. There are no post Paleozoic additions to the coast north of Long island.

On the other hand, the continent has grown westwardly by the uprising of successive mountain chains from a line not far west of the present

Mississippi, adding broad areas of Secondary and Tertiary rocks. In the same way Asia is bordered by ancient rocks from Bering strait to Corea, which extend in part to the shore in rias coasts and sink from its high lands by great step-faults to the sea. On the north they formerly extended farther eastward, and are now submerged. On the western side late elevation has raised the broad Tertiary seabottom which separated Europe and Asia and extended the great continent to the Urals.

Europe, the smallest continent, with the most complex structure, has the Urals on the east, of the same age and character as the Appalachians and the southeastern mountains of Asia, and folded Tertiary rocks toward the west and south. It has lost nothing east of the Urals and gained nothing beyond the old Caledonian chain on the west; and coinciding herewith, there is no lateral shifting in relation to Africa.

Moreover, the western half of Australia is unfolded tableland of Archean age, and this lies due south of the Manchurian boss, and the eastern area to and including New Zealand is folded land made much later. There is thus no torsional motion between the two semi-continents—an idea suggested largely by the great curved island chain joining them, which receives independent explanation.

On the other hand, South America has grown westward, and yet the whole continent is east of the middle line of the Canadian protaxis, and and if such an eastward thrusting of a continental mass were anywhere conceivable it would be here, where the lofty, sharply compressed Andes indicate a powerful thrust, and where the recently sunken southern Pacific may have furnished the force.

Moreover, the deepest water of the Pacific is off the Asian coast, that of the Atlantic off the American coast, and we have in the line of deep sinkholes below the level of the sea—the Caspian and Aral—a reminiscence of the Tertiary time, when the deepest water of the Tertiary ocean bordered the eastern shore of Europe. Now, the deepest sinking of the oceans is not the cause of the highest mountains on the adjacent lands. Indeed, no mountain chains can be correlated with those depressions.

It had seemed possible that a different mode of the cause proposed by Green might be effective at times and under most favorable circumstances, at least by aiding or opposing the larger forces of contraction to produce the conditions under discussion, namely, sinking of eastern and rising of western coasts. A sinking sea-bottom may exert force east and west as a wedge, and additional or differently directed force east by inertia. Sometimes the sinking may be rapid enough so that some part of this force may be effective. Land rising with some suddenness in an eastern coast would lag to westward. Adjacent sea-bottom, sinking, would advance to eastward. They would tend to separate. This might produce stretching, torsion, and blockwise sinking along this coast, and explain many of the peculiarities of the east coast of Asia and America, the deep ocean bottoms, the rias coasts, the deep "graben" like the Fossa Magna of Japan, and the down-faulted blocks which preserve the Trias of the Atlantic coast.

On the other hand, on a western coast the rising land moving west and sinking sea moving east would tend to approach each other, and this would add itself to the direct landward mountain-making thrusts which were active along this coast. Moreover, the tidal stresses, which will be discussed below, would combine with the forces here invoked to cause the crumbling down of the eastern coasts and the upfoldings along the westward ones, along all northeast and northwest lines.

My colleague, Professor A. L. Kimball, has made for me the calculation that in an ocean 500 miles wide a sinking of the bottom one foot per second would produce an eastward force of only 1,080 pounds to the square foot per second; a sinking of one foot per minute would produce a force of 18 pounds per square foot per second, and so on. This is a force so small that it may apparently be neglected except under most favorable circumstances.

PART II. THE ZONE OF THE INTERCONTINENTAL SEAS

SUGGESTIVE RELATIONSHIPS OF LAND AND SEA AREAS

To an observer approaching the planet from the depths of space a most striking thing would be the three great triangular elevated land masses projecting south, the three great depressed oceans tapering north.

If we add the Arctic ocean and the Antarctic continent, and consider the antipodal arrangement of land and water, the tetrahedral disposal of the mountain chains and of the main divides as shown by Von Tillo,* and consider further the geodetic measurements and pendulum observations which make the earth taper at the south pole and emphasize the lightness (that is, elevation) of the continents and the excess of gravity (that is, depression) over the oceans, so that the ocean surface is in a certain sense a concave surface, sinking from the continental borders, and note finally the central lines of volcanoes which mark lines of fissuring down the centers of the depressions, we may say that the tetrahedral plan in the evolution of the earth's feature lines is strongly suggested by simple observation. It is imperfectly realized, to be sure; but we may use the tetrahedral idea as a working hypothesis, and deduce that as the three continents have had a common origin, the three homologous mediterraneans that bisect them have had a common cause; and, conversely, that if this cause had not acted the continents would have been left in more continuous masses, thus filling out more perfectly the tetrahedral pattern.

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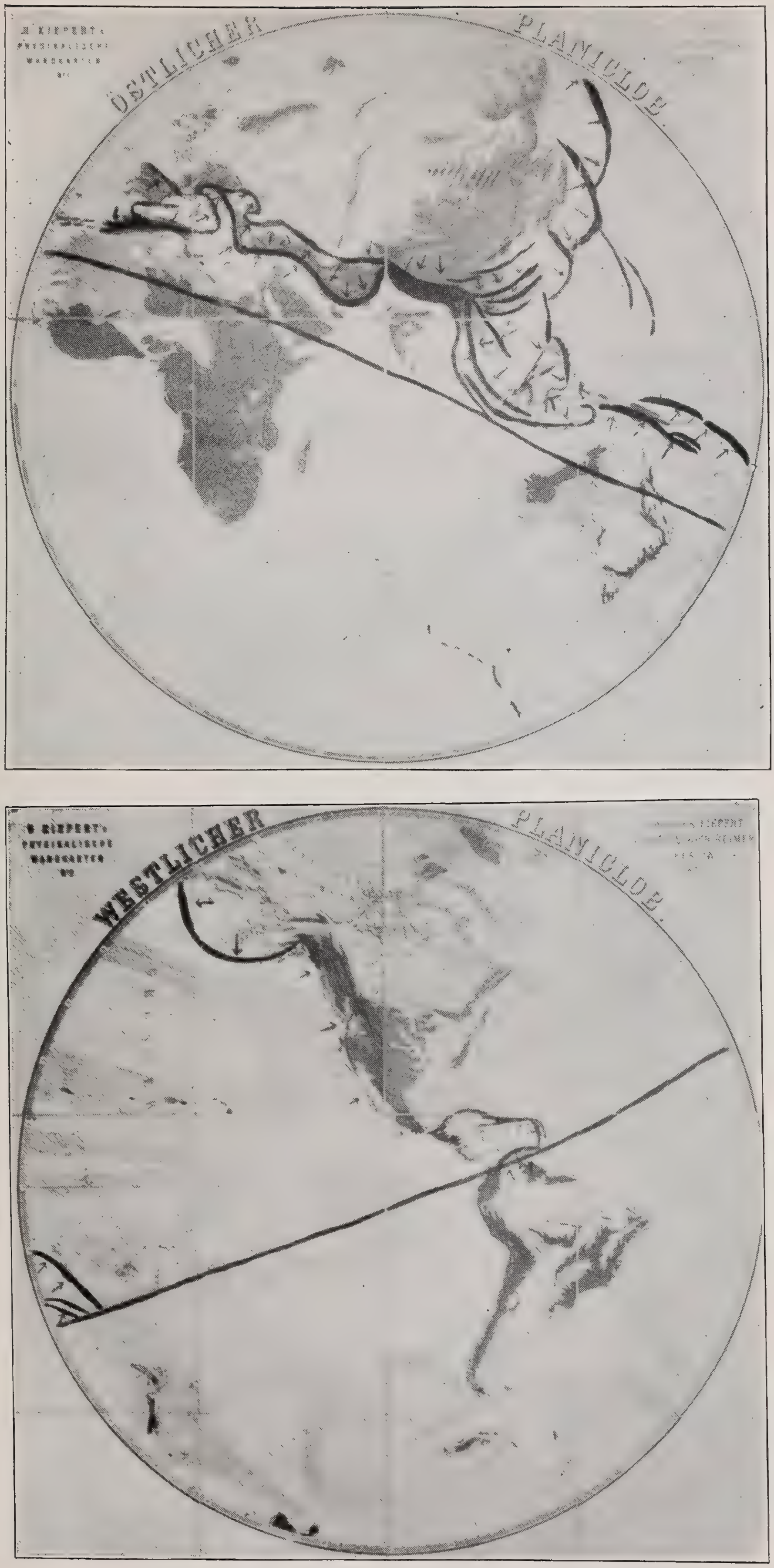
*Petermann's Mittheilungen, 1887.

There remains, then, for consideration, the fascinating question of Green's twinning plane, the great mediterranean band of seas broadly bisecting the three continents, of loftiest mountains and deepest depressions, of torsion and vulcanism, which belts the earth parallel with the ecliptic.

GREEN'S EXPLANATION OF THE MEDITERRANEAN ZONE

If we place a globe with its axis inclined 23½ degrees from the vertical, so the wooden circle will be the ecliptic, and rotate it so Gibraltar is beneath the pole and the brass meridian, the small circle 12 degrees (plate 14) north of the horizon is the center of the most remarkable zone on the earth. Beginning with the Mediterranean and all its mountain chains, deep basins, and volcanoes, it continues past Asia Minor, the Caucasus, Himalayas, East Indies, the volcanic band of the south Pacific, to the Central American-Caribbean region, and by the Azores and Canaries to Gibraltar again. It is cut at the East and West Indies by the equator and the zone of fire bordering on the Pacific. The explanation whereby Green connects the phenomena of these two circles with his hypothesis is exceedingly ingenious and acute. He makes use of the polar circle fractures of Richard Owen and Dana, and the ecliptic fracture zone of Guyot and Hochstetter, caused, he believes, by tidal strains in the earth's crust.

If we refer again to the globe, placed as before (figure 6), with the axis inclined 23½ degrees and the sun and moon placed as indicated, the sun will be in solstice and the moon in opposition, and it will be the time of spring tides. There would then be a maximum tidal stress in the crust along the great circle 90 degrees from the sun and tangent to the polar circle, indicated by the line *AB* in the center of the figure. The solstice is the solstice because the sun stands longest here where ecliptic and equator are parallel, or nearly so, and this strain would be applied daily for a much greater portion of the year beneath this circle *AB* than beneath that due to any other position of the sun except the other solstice, *CD*, where the effects would be identical with *AB*, and there would therefore be more conjunctions and oppositions here. The relative distribution of this strain through the year is indicated by the increasing depth of shading from the pole, *NS*, to the two lines *AB* and *CD*—that is, from the equinoxes to the solstices. Now every portion of the earth would feel this stretching equally as it passed beneath the line *AB* each


H. KIEPERT's PHYSIKALISCHE WANDKARTEN
ÖSTLICHER PLANIGLOB.
H. KIEPERT's PHYSIKALISCHE WANDKARTEN
WESTLICHER PLANIGLOB.

MAPS OF THE HEMISPHERES

Showing position of equator when pole is on Arctic circle just west of Bering strait, and axes of mountain chains along zone of intercontinental seas and around north Pacific, and direction of their motion in folding.

day, and the constantly repeated stress would search out planes of weakness in the crust, and might change them to fractures, as the constant bending of a wire at last breaks it; as a weak joint in a bicycle chain is constantly strained as it goes over the geared wheel and at last broken.

As we now revolve the globe beneath the vertical wire, many northeast and northwest coastlines, which are assumed to be fracture lines as well, come under it. If we halt the globe so that Gibraltar is again beneath the solstice, the Pacific coastline of Asia, the most remarkable and certain fissure line of all, comes under the line *AB*. Indeed, the whole band of fire around the Pacific is nearly under this line. And it seemed to Green that the maximum tidal wave thus regularly and repeatedly passing through this coastline where the slope changes so rapidly might intensify any existing tendency and cause fracture.

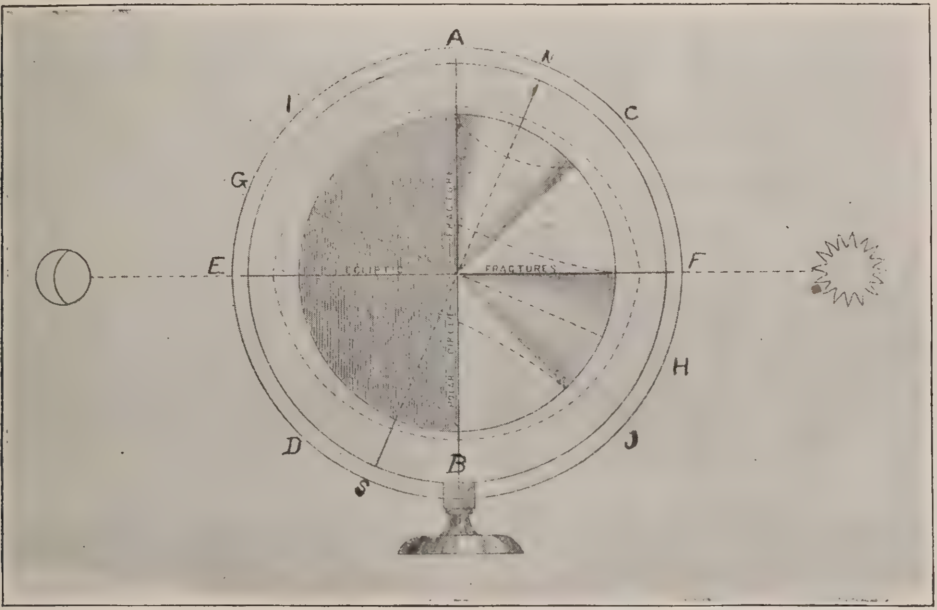


FIGURE 6.—*Diagram of the Globe placed so that F is in Solstice.*

To illustrate tidal stresses.

But the same tidal stress tends also to produce cleavage at right angles to the above plane, and thus parallel to the ecliptic, *EF*. This stress decreases from equator to pole. There is set up a horizontal differential strain between each element of the crust—that is, a narrow band nearest the horizontal circle is stretched most, the next band above a little less, and so on north and south, causing a tendency to rupture between the bands. This force would also reach its maximum in the solstitial ecliptic plane, as is indicated by the shading between *EF* and *IJ*, and might search out planes of weakness on the earth's surface along great circles tangent to the tropics.

And this was the interesting coincidence that Green utilized. At the instant when what we may call the vertical tidal stretching was causing the polar circle fracture around the Pacific, the horizontal tidal shearing would tend to produce ecliptic fractures along the Mediterranean zone, since this lies parallel to the ecliptic when the Pacific coastline is perpendicular thereto.

Indeed, Green assumed that if the Pacific coast was thus fractured by the tidal stress (and this seemed to him certain) a set of fractures at right angles thereto, or ecliptic fractures, would necessarily be formed coincident therewith and extended clear around the globe, and thus the twinning plane was formed.

The southern hemisphere, tending to move eastward parallel with the equator, as explained on page 67, utilized this plane of fracture parallel to the ecliptic, and moved the southern continents along it to their present position, and thus the twinning plane was used.

This furnished a consistent and extremely ingenious theory and connected a great multitude of diverse phenomena with the tetrahedral idea.

TIDAL STRESSES IN THE CRUST

Although we are not able to assign an important place to torsional forces and tidal stresses in the formation of the intercontinental zone, we have wished to explain Green's hypothesis thus fully for the consideration of others, because of its curious interest, and because it brings up the subject of tidal stresses in the earth's crust.

If these tidal forces have transferred the moon from a place near the earth to its present position, their reaction must have been in some wise effective in the earth's crust and more and more effective as we go backward in time.

If this force were able, acting alone, to produce fissures, it would form a close set tangent to the polar circles, and covering the face of the earth like the engine-work on a watch-case, and breaking the crust up into diamonds with angles of 47 degrees directed north and south. The tendency of the tetrahedral deformation is to produce triangular land-masses with the apex southward. In combination the tidal force may tend to emphasize and duplicate these southward triangles. Where the Atlantic coast type prevails in the Atlantic and Indian oceans, coast formation is largely by sinking of great land blocks, and the tidal strains may be influential in choosing or directing the course of fissures otherwise caused, and thus be partly responsible for the prevalence of northeast and northwest coastlines. We recall India, Greenland, and the south lobes of the continents. It seems also possible that this tension, acting transversely to the northwest and northeast mountain chains and sharply sloping coasts, has been among the directing forces in fixing their position and determining the constant repetition of parallel or superimposed chains during long geological ages (see Prinz's map, page 94).

POSSIBLE FORMER PARALLELISM OF EQUATOR WITH MEDITERRANEAN ZONE AND GREATER OBLATENESS AS AN EXPLANATION OF THIS ZONE

Presentation and discussion of views of other writers.—The tidal force was assumed by Green to be capable of making fissures in the crust. Granting this, the necessary connection of the two sets of fissures was assumed, and, while there is a possible reason for the occurrence of fissuring in the vertical zone, in that it coincides with maximum bending or sedimentation at a coastline, there is no reason apparent why this particular position of the ecliptic plane bisecting the three continents was a plane of weakness rather than any other.

Moreover, granting such a plane of weakness, the shearing force generated by rotation parallel to the equator, *GH* of figure 6, page 79, would act at great and perhap sprohibitive disadvantage at an angle of 32½ degrees to its proper direction in the plane *EF*.

I was thus led to consider, although at the same time dismissing the idea of torsion, the alternate hypothesis or speculation that this zone was once the equator or parallel to the equator, the earth rotating, like Jupiter, with the equator and ecliptic nearly coincident, which would make these stresses a maximum both for the Mediterranean and the Pacific zones. As theory does not permit to the earth so small an obliquity, I pursued the inquiry without regarding the amount of the obliquity, since there are many peculiarities concentrated in this remarkable band which may possibly find explanation if it were an equatorial zone. This would shift the pole north beneath the brass meridian to a point west of Bering strait, and the center of the equatorial ring would be on the line crossing northern Africa on the map in plate 14, page 78. I was then interested to recall that other students, working in different fields, had come upon results which demanded a transfer of the pole into much the same region.

The first suggestion of this position of the earth's axis came from Kloden,* who pictured the earth as a fluid and motionless body, egg-shaped from lunisolar attraction, which began to revolve slowly on solidification. As rotation increased the pole moved to its present position.

Doctor J. Evans, in a presidential address before the Geological Society of England,† supposes an equatorial mountain chain raised across the north of Africa, crossing the meridian of Greenwich in 20 degrees north and the equator in 90 degrees east and west longitude, and asks would not this bring the axis of figure and rotation 20 degrees south between Greenland and Spitzbergen? The paper was discussed by J. F. Twisden[*] and several others, and no one seems to have noticed that this would carry the axis of figure 20 degrees in the other direction, namely, to near Bering strait.

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*K. F. Kloden: Grundlinien zu einer neuen Theorie der Erde. Berlin, 1823.

† Quar. Jour. Geol. Soc., vol. xxxii, p. 108.

From a study of the Tertiary leaf beds of Mackenzie river, Grinnell land, Disco, and New Siberia, Melchior Neumayr, of Vienna, proposed to shift the pole 10 degrees toward Bering strait to explain the distribution of these subtropical plants in Arctic regions; and Baron Nathorst, of Stockholm, from a study of the Tertiary flora of Japan, found that the distribution of Miocene plants could best be explained by a transfer of the pole 20 degrees toward the same point.[†]

Jules Peroche, in a study of all the fossil floras, lets the pole approach Bering strait as it revolves in a circle of 30 degrees diameter around the magnetic north pole.[‡]

There appears in Zeitschrift der Deutschen Geologischen Gesellschaft for 1899 [§] an article by Max Semper, in which the attempt is made to reconstruct the ocean currents of the Eocene and to compare therewith the direction taken by the Eocene mollusca in their wanderings. He finds entire lack of agreement. The currents, however, take directions which favor the known wandering of the East Indian genera westward across the Mediterranean and on to Central America, when the pole is transferred 20 or 30 degrees along the meridian 20 degrees east of Greenwich. This brings the pole into western Alaska and very near the point assumed in the foregoing discussion.

Last year Michel-Lévy [‖] published a remarkable map, (plate 13, page 74) showing the distribution of volcanic rocks and main mountain chains and fissure systems in tetrahedral symmetry, and placed the pole of the tetrahedron 18 degrees from the earth's pole, near Bering strait.

Mr Osmond Fisher first suggested that the lessened oblateness should have produced corrugation, and that the lack of indication of any effect such as might have been expected in equatorial regions favors a change of latitude,[¶] but he dismisses the subject in a sentence.

Mr W. P. Taylor,[**] in a valuable article admitting and enforcing the arguments against the sufficiency of the contractional hypothesis to explain the folding of the earth's crust, replaces this by the theory that by the diminution of the oblateness dependent on slower rotation the mountain folding could be fully accounted for. Admitting, with Lord Kelvin and Darwin,* that the axis of rotation and maximum inertia of the earth may have moved to any amount, and noting that the highest mountains in the Andes and Himalayas are near the tropics and apart from the equator, he suggests as a mere speculation that if the pole may have been in the remote past transferred to Bering strait, bringing "Guyot's central zone of fracture" (that is, the Mediterranean zone) to be the equator, the highest mountains would be brought much nearer the equator. This could be "only a shifting of the mass of the earth (so to speak) upon an axis fixed in angular direction, with accompanying shifting within its substance of the equatorial plane of oblateness." That is, the obliquity of the ecliptic must remain unchanged.

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[*] Quar. Jour. Geol. Soc., vol. xxxiv, p. 35.

[†] Koken: Die Vorwelt, p. 539.

[‡] Mem. Soc. Arch. et d'Hist. Nat. d. l. Manche, vol. vii, 1866.

[§] Volume li, p. 185.

[‖] Sur la coordination et la répartition de fractures et des éffondrements de l'écorce terrestre en relation avec les épanchements volcanique. Bull. Géol. Soc. France, 3 S., vol. xxvi, 1898, p. 105.

[¶] Physics of the Earth's Crust, 1881, p. 183.

[**] Crumpling of the earth's crust. Am. Jour. Sci., 3d series, vol. xxx, 1895, p. 250.

We may look for other indications that this zone inherits its manifold peculiarities from its former equatorial position.

1. It is at first curious that the great chain of the Aleutians is concentric with the proposed position of the pole.

2. In the short distance between Scotland and the Mediterranean are: (*a*) The Caledonian chains with the great overthrusts of Eribol, and folds of this age are continued south to the Ardennes; (*b*) the Variscan chains with the great overthrusts of the Belgian coal fields, and folds of this age are buried beneath the later Alps; (*c*) the Armorican chains, and (*d*) the Tertiary folds of the Alps and Apennines, the latter series representing a crustal shortening of 74 miles, according to Heim. All are thrust northwardly.

The sinking of the Mediterranean region and shrinkage beneath this area seem incompetent to this work.

The inadequacy of the escape of heat to explain all folding, so strongly enforced by Fisher,† Dutton,‡ and many others, may be for the moment admitted,§ and we may review the list of possible causes of crustal shortening given by Van Hise* (omitting those due to tidal retardation and noting that the reserves of all these forces had probably been exhausted during the post-Carboniferous revolution), namely, (*a*) some fraction of the diminished result of secular cooling admitted above to be unimportant; (*b*) cementation, and (*c*) escape of lava and gases. Their probable amount of accumulation in the Mesozoic seems insufficient to explain the enormous amount and the peculiar localization of the above Tertiary deformation.

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* Darwin admits an excursion of the pole of 10 or 15 degrees, and suggests its standing over Greenland to explain the Glacial period. This wandering would be by steps of two or three degrees, followed by an earthquake assisted adjustment to a figure of equilibrium. (G. H. Darwin: On the influence of geological changes on the earth's axis of rotation. Phil. Trans. Roy. Soc., vol. clxvii, part i, 1877, p. 271.)

† Physics of the Earth's Crust, 1889, p. 255.

‡ A criticism of the contractional hypothesis. Am. Jour. Sci., 3d series, vol. viii, 1874, p. 113.

§ This argument, based on a solid sphere of uniform initial temperature, cooling by conduction according to a constant law of conductivity derived from imperfect experiments at low pressure, involves more, and more improbable assumptions than does the hypothesis that the interior of the earth may consist of highly condensed gases at temperatures above their critical points, an hypothesis first advanced by Franklin (Conjectures concerning the formation of the earth: Trans. Am. Phil. Soc., vol. iii, p. 1) and developed by Ritter in a wonderfully acute and original mathematical analysis (Untersuchungen über die Höhe der Atmosphere und die Konstitution gasförmiger Welt-

Thus the effects of tidal retardation, reserved above, seem a welcome addition to the means of explanation of the crowded equatorial chains in question.

3. It is significant that Dutton, denying the efficacy of shrinkage, advances an hypothesis of mountain-making by horizontal flowage at the expense of a somewhat forced hypothesis to explain a potential slope along which the movement may take place. Great masses of sediment are transferred from land to adjacent sea-bottom. "The result is a true viscous flow of the loaded littoral inward" and upward "upon the unloaded continent."†

Sir John Murray, in a presidential address before the Section of Geography of the British Association, has adopted and extended this theory.‡ The subcrust (tectosphere or melted layer) of the loaded margin becomes more solid by increased pressure. The subcrust of the unloaded land becomes viscous by relief of pressure. "Deep-seated portions of the terrigenous deposits are slowly carried toward, over, or underneath the submerged land." These newly formed terrigenous shore deposits had become by decomposition and sorting highly silicious and lighter, and by many repetitions of this process are carried from the shores into the interior of the continents by a kind of arenaceous diffusion, making the latter more silicious and lighter.

4. If we review again the series of paleographical maps (plates 10 and 11, page 70) we shall see that, while the present equator has never been emphasized as a line of importance in the ancient geography of the earth, the Mediterranean zone was marked out in very early times. From the Paleozoic era to the present, one of the most persistent features shown on these maps is the continuous band of water which has occupied the

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körper. Ann. d. Phys. u. Chem. 2, vol. v, pp. 405, 553; vol. vi, p. 135; vol. vii, p. 304; vol. viii, p 157.)

The theory has been popularized by Zöppritz (Ver. d. deutsch. Geographen Tages, 1882, p. 15), and accepted by Gunther (Lehrbuch d. Geophysik, vol. i, 1884, p. 319). It demands a vastly greater central temperature and gravity, and would introduce an unknown coefficient of contraction and a cooling by convection, and permit an indeterminable surface contraction.

*Journal of Geology, vol. vi, 1898, p. 10.

†Greater problems of physical geology: Bull. Phil. Soc. Washington, vol. xi, p. 60.

‡Nature, vol. lx, 1899, p. 525.

position of our supposed equator and has been bounded north and south by more or less continuous bands of land. It is the "Centrales Mittlemeer" of Neumayr. Indeed, in the Eocene many groups of littoral animals can be followed along the continuous shores of this nummulitic sea from India through the Mediterranean to Panama, and in the Cretaceous the Rudistæ had a similar distribution. We may assume the former greater rotation of the earth with the pole at Bering strait to have stood in causal relation with these bands of land and this continuous belt of water. This is an added argument for the supposed position of the pole.

5. The Mediterranean zone, with its deep depressions and curved mountain chains with volcanoes on the concave sides, finds a possible explanation in the assumption that these chains may have slid down or have been thrust down the northern slope of the former greater equatorial protuberance, as it subsided because of the diminishing velocity or because of readjustments dependent on the motion of the pole toward its present position.

Is such a slope possible? The equatorial sea, described in the last section, which continued into the Eocene, may be taken as an indication of greater velocity, and thus of greater oblateness.

Darwin makes the life of the planet begin about 57,000,000 years ago, with a rotation of 5¾ hours, which in about 10,000,000 years had come to be 15½ hours. Plotting his values and continuing the curve to the present date, we get as maximum values a day of about 19½ hours 25,000,000 years ago, and 22½ hours 10,000,000 years ago. Darwin, in discussing the table from which the above values are taken, expresses the opinion that some part of these changes, referring mainly to the numbers mentioned in the first part of the above statement, could have taken place in geological time.*

In the article cited above Taylor makes the oblateness when the earth rotated in 6 hours 396 miles greater than at present.

At the instance of Professor Van Hise, Professor C. S. Slichter † calculated the oblateness of a homogeneous spheroid rotating in 5½ hours to be 113 miles, and the surface 210,000 miles greater than at present on that account, and on the assumption of a heterogeneous spheroid and Laplace's law of the relation of density and pressure and a rotation period of 5½ hours the "changes of pressure" would in addition cause a minimum increase of surface above the present of 1,700,000 square miles.

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* G. H. Darwin: On the precession of a viscous spheroid and on the remote history of the earth. Phil. Trans. Roy. Soc., vol. clxx, part ii, 1879, pp. 494, 581.

† Jour. Geol., vol. vi, p. 60.

Van Hise suggests that the effect of the loss of these two great amounts of surface would be mainly concentrated in equatorial regions, and is available to explain the great deformations of the older rocks, especially those of the Archean and Algonkian.*

In our ignorance of the real amount and the rate of decrease of this large oblateness and the rate of lagging of its plastic adjustment to diminished rotation, we may assume that some small but sufficient part of this equatorial protuberance may have continued later than the Algonkian and furnished the slope required, in this explanation, at least for the earlier chains formed along this line,† and later chains tend strongly to be superimposed on earlier ones.

Later it may have been reenforced by elevation due to contraction—that is, to tetrahedral deformation.

General explanation of the formation of the intercontinental zone.—While the equatorial ring by long tidal ages of friction was being reduced to near its present dimensions (and both Spencer and Darwin,‡ in opposition to Lord Kelvin, admit a rapid plastic adjustment of the oblateness to the diminishing rotation), the northern tetrahedral land masses, increased by constant cooling, might come into relative prominence, and solar attraction acting upon them might slowly bring the rotation axis into its present position of equilibrium and coincidence with the tetrahedral axis, keeping the attractions in the northern and southern hemispheres equal. This might ultimately aid, as Green has shown, in causing the axis to incline 23½ degrees to the ecliptic and to move into its present position. During this change came the marvelous time, ending in late Miocene and even Pliocene, when the great mountain chains rose along this zone, obliterated the nummulitic sea, created the great chains from the Pyrenees to the Himalayas and on to the north of Australia; when part of the plateau of Arabia and western Persia rose and limited the Indian ocean on the south; when the Central American chains and the Antilles arose and separated the Atlantic and the Pacific, and when perhaps a continental mass sank in the south Pacific coral region. Coincidently Andes and Cordillera and the festoon of curved chains that adorns Asia surrounded the Pacific with a wall of mountains and a line of fire. It is a pleasant suggestion of Sacco § that the human race may have originated about this time in the East Indies, and a French savant, M Manauvrier, has suggested that *Pithecanthropus erectus* may have obtained his expanded skull by the assumption of the "marche bipède" to which he was compelled by the intense volcanic activity in Java, thus connecting the advent of man with the advent of vulcanism.*

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* Jour. Geol., vol. vi, p. 56.

† In the zone of Mont Blanc and in the Carinthian Alps, Variscan post-Carboniferous folds appear beneath the Alpine Tertiary folds. (Suess. See appendix to this paper, p. 100.)

‡ The Tides, p. 301.

§ Essai sur l'orogénie de la terre. Turin, 1895, p. 47.

† A broad zone of unfolded table-lands, often Archean but partly covered by flat rocks from eustatic transgressions, which have been since a time long antecedent to the upfolding of these mountain chains unaffected by orogenic forces, stretches south of these chains, including north Africa, Arabia, India, Australia, and Guiana (see plate 14 *a*, *b*, page 78), and represents the central portion of the equatorial elevation which, as tidal friction retarded the earth's rotation, became partially unsupported, and, in sinking, furnished the northward thrust which has raised up Alps and Antilles upon its flank, or, resisting collapse up to the strength of its material, allowed the more plastic superficial strata to flow north in mountain folds according to the acute suggestion of Reyer,‡ that mountain chains seem not like the effect of tangential thrust, but like the result of the sliding of slightly plastic strata down a low slope under the influence of gravity. A first effect may have been the sinking of large blocks at spots along the slightly unsupported slope of the flattening ring forming the deep pockets so peculiar to all the Mediterraneans. Then perhaps the gathering of sediments around the borders aided in the formation of the mountain chains which surrounded the sunken blocks. Then followed the general sliding or succession of slidings of the whole series northward down the slope, forming the mountain chains and island chains often circumjacent to the sunken blocks which belt the earth along the Mediterranean zone, and causing all the volcanic and seismic activity which is concentrated along the concavity of the curves.

This sliding might be carried down a very low slope, solicited, as it were, by the constant stresses of the earth tides and occasional earthquake vibrations, especially in soft and water-soaked strata recently emerged from the sea.

Finally came the sinking of great blocks of these chains where they had come to rest on portions of crust unequal to their support, as where the Apennines cross into Africa or the Caucasus sinks in the Pontus and the Caspian, or where the northern Adriatic and Ægean have sunk in whole or part almost within the recent period.

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* Am. Jour. Sci., 4th series, vol. iv, 1897, p. 237.

† We present the following conjectural explanation in the indicative for brevity and directness, noting that the more conservative idea that only the early outlines of these chains were dependent on this position of the slope of the sinking ring is perhaps more defensible, and noting also that the suggestion of this relation retains a certain plausibility apart from the success or our explanations.

‡ Theoretische Geologie, 1888, p. 479.
Ursachen d. Deformationen und d. Gebirgsbildung, 1892.
Geologische Experimente, Heft iii, 1894, p. 9.

It may be asked why this zone of sinking and compression appeared only on the northern slope of the former equatorial ring, and the answer would be that as the equator moved southward across Africa the diminished protuberance was carried to its present position, producing here an opposite tendency to elevation and rest.

The maps show (see plate 14, page 78) the areas between the former and the present equator to represent the longest east-west reaches of the passive tablelands characterized by the absence of folding and by the vertical sinking of great blocks, like the Dead sea, the Red sea, the Aden gulf, and Tanganyika, in all this agreeing well with its assumed relations.

Particular description of the zone with discussion of the exceptional character of the Asiatic chains.—Around the Mediterranean we know the great mountain chains east to the Caucasus are moved mainly northwardly because they bend in great loops convex to the north between the resisting forelands of Auvergne, Bohemia, and the Sudetic ranges. This is the conclusion of Suess. If they had been caused by a thrust from the south, the most compressed and overturned chains would be, as in the Appalachians, nearest the causative force, or on the south. If they had been caused by moving as a plastic mass down a slope, the most compressed chains would be at the north. The latter case is the true one, as the most comprimated and overthrust chains are the northern Alps, as in the Tödi-Windgällen group or north of Mont Blanc. This is the suggestion of Reyer. It is as if the old land of Africa has most resisted collapse, making a low slope down which the mass moved, forming the strongest chains at the front of the sliding where the forward motion has been greatest. There was locally partial thrust to the south, as the sinking blocks acted like the toggle-joint of a primitive printing press, and gave southward motion to the Atlas.

Such a local sliding to the northwest seems well established for a great area of the western Alps, where between Geneva and lake Thun and probably much farther in both directions and with the full width of the line between Martigny and Vevay the Mesozoic rocks have slid out 20 kilometers over the Tertiary foreland and rest now rootless on Flysch and the red Molasse. They have torn off and transported great masses of the crystallines off which they have come.*

In Asia, on the other hand, from the Caspian to Molucca, as there was, because of the tetrahedral depression, no sufficiently extensive land on the south to oppose itself to the effect of the depressed Indian ocean and of the continued elevation of the Manchurian shield—the tetrahedral nucleus of this, the largest continent—the many parallel mountain chains of southern Asia and the East Indies have, as it were, flowed southward from this shield like a glacial ice-cap and ended like a lobed ice-front, overflowing and wrapping in great curves around the resistant foreland of India. We must assume the elevation of the Manchurian shield on the one side and the sinking of the Indian ocean on the other to have given the slope.

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* M. Lugeon : Les grandes dislocations des Alpes de Savoie. Archives des Science phys et nat. 4 Period 2, 1–4, 1896. Review. Neues Jahr. 1899, 2d vol , p. 404. H. Schardt : Die exotischen Gebieto, Klippen, und Blöcke am Nordrande der Schweitzer Alpen. Eclogæ. Geol. Helv. V. 233, 1898. Review. Neues Jahrbuch, vol. 1, 1900, p. 87.

We have considered but a small fraction of the chains which have flowed out from this Asian center, and it does not seem possible that any thrust from that area can have caused them.

Since this paper was written I have read the abstract of an article by Suess, in which he defines an ancient horst in the center of southern Siberia bordered by a fault which runs along the Jenissei from Krasnojarsk north to the mouth of the Stony Tunguska and extends east to a southwest-northeast fault or fold in the Jablonnoi mountains east of lake Baikal. This forms the northwestern part of the Manchurian shield as defined above. He considers it the center from which the Asian curved chains from Saghalin to Java and on through the Himalaya to the Persian gulf have flowed outwardly toward east, south, and west, accepting the hypothesis of Reyer. In some way not made clear, North America, and especially the magnetic north pole, is made the center toward which a complementary inflow has taken place, across where is now the Pacific, and Suess suspects that these curved Asian chains "stand in some kind of relation to an outflow of superfluous earth-mass from the pole—that is, with a flattening of the same."*

In the Banda sea the southward curvature changes to a northward, causing one of the deepest spots in the ocean bottom, and the bending is then to the north away from the old land of Australia, and this northward curve is repeated in many island chains on the north to the Marshall archipelago. This curve is continued from the mountain range of New Guinea to New Hebrides and New Caledonia. Here the line leaves the continental area with its curvilinear island chains, and enters upon the ocean bottom area with its islands in detached groups, and from Fiji to Tahiti follows the line of volcanic archipelagoes. Off to the north lies the coral island area, separated by Dana's line, and the Kermadoc-New Zealand-Macquari band branches off to the south, as does the

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* See appendix to this paper, p. 96.

Celebes-Philippine volcanic band to the north. The line then passes the Marquesas, where gneiss is said to be found, and reaches the Galapagos islands.

Finally, the Antillean system and the mountains of Venezuela seem to have slid in great curves northward from the ancient land nucleus of Guiana toward the deeper part of the Altantic.

The remarkable demonstration suggested by Von Seebach* and completed by Hill†, that the Antillean system is continued westward across Central America, truncating the Cordillera south of the plateau of Mexico and separated from it by a line of volcanoes, and independent of the Andes and separated therefrom by a line of volcanoes, and completes the evidence that this is a continuous band around the globe of mountain-making, blockwise-sinking, and vulcanism, repeating a common Mediterranean type as it intersects the three continents, and continuing across the oceans in submerged ranges and lines of volcanic fissures.

Homologies of the Mediterraneans.—We may finally allude to another series of homologies which attest the common origin of the features of this remarkable line.

The Mediterranean depression, located at the solstitial point, from the western basin to the Black sea lies parallel to the zone in the solstitial position, and only the sea of Azof breaks through the mountain curve on the north. The East and West Indies, placed at the equinoctial points, where equator, the intercontinental zone, and the Pacific line of fire intersect, make the same large angle with the zone. The curved Banda group is exactly homologous with the curved volcanic group of the Lesser Antilles. The Banda sea is the homologue of the Caribbean. Celebes projects north like Honduras. The Celebes sea is like the Bartlett deep, and Borneo stretches north to the Philippines, as does Yucatan to the Greater Antilles; and the China sea lies outside the curve of mountains, as does the gulf of Mexico. Cuba and the Philippines are then quite close homologues, and we have assumed political control of the two nodal points on the earth where all natural phenomena are at their maximum—the land of the Royal palm and the Spice islands, of the tornado and the hurricane. We are assured an abundance of atmospheric, seismic, and volcanic violence for all time.

Diversity of eruptives.—In the text connected with the map cited above, Michel-Lévy, in classifying the larger mountains and fracture systems, separates the zone we have just followed as a distinct type, marked by rounded depressions (effondrements en ovales méditerranéans), characterized by the great diversity of igneous rocks, contrasted with the elongate Andean type, which is distinguished by the monotony of the effusive rocks over large areas.

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* K. von Seebach: Ueber vulkane Central Amerikas. Ab. Ges. der Wiss., Göttingen, vol. 38.

† R. T. Hill: Nat. Geo. Mag., vol. vii, p. 175.

Mountain chains of two types.—The contractional hypothesis is doubtless the best we have for the explanation of mountains; but in this time of the foundering of the whole crust of the earth it was greatly overworked, and it would be a distinct relief if a large and peculiar group of orographic forms could be thus explained in another way, and one which involves perhaps less depth of movement and can be best harmonized with the great diversity of the volcanic products. We would put in the group of mountains of flowage those of the zone we are studying and the Asian side of the Pacific band. They are convex in direction from the center of motion, and have often flowed toward the sea. They are most folded on the convex side, farthest from the center of motion, and lessened folding, stretching, and fissuring with frequent outpour of lava appear on the concave side nearest the center of motion.

The other group, including the Appalachians, the Urals, and the Cordillera, are formed by tangential thrust of the sinking sea-bottom, are straight or even concave (Urals, and Appalachians in crossing the Mississippi) on the side away from the center of motion, and have always moved from the sea. They are most folded on their straightest or convex side, nearest the center of motion where the force was applied, and do not have volcanoes on the concave side, and the folds die out on the side farthest from the center of motion, as in the Cincinnati uplift, or Parma, as Suess calls these low folds from the corresponding one in the Urals. The Great Basin topography we may hold with Suess * and Lundgren to be caused by the collapse of a great Parma extending from the Wasatch to a line east of the Rocky mountains, and the Uinta and the smaller peaks east to the Rockies to be horsts remaining at the higher level, the whole formed as the ice in a drained pond collapses around the large rocks on the bottom.

The Pacific zone—We have finally to consider the chains bounding the north Pacific ocean (plate 14, *a* and *b*, page 78). Too great stress has been laid on the distinction between an Atlantic and Pacific coast type, and the violence of the forces around the Pacific have produced a continuous line of volcanoes, which disguises the diversity between its two shores. Indeed, in the article given below Suess, the author of the distinction, seems to recede from the position that the mountain chains have flowed toward the sea on both sides of this ocean. There seems to be substantial agreement among the American and Canadian geologists who have studied on the Pacific slope that the forces which have produced the mountains there came from the sea. There seems to be substantial agreement among those who have studied the Asiatic shore that the mountain-making force came from the land. There is little resemblance between the continuous Cordillera and the series of imbricated curves which adorn the Asian coast. It was an added wonder of this wonderful Miocene period that the Pacific was girdled with mountain chains and volcanoes at the same time with the equatorial belt we have studied and bisecting it at right angles, and it was an advantage of Green's explanation that it brought these under a common cause.

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* Das Autliz der Erde, vol. i, p. 734.

The primary force raising the chains about the Pacific would be the wedging from the sinking of great areas of the Pacific sea-bottom, preceding more or less truly, according to the norm of the tetrahedral deformation.

The second force would be that derived from the inertia of the moved blocks as defined above (see page 76), which if ever effective would, both as embodied in the sinking sea and rising land (and thus doubled) tend to increase the efficiency of the mountain-making force along the American shore. Along the Asiatic shore the effect might be, in any time of most rapid sinking (and evidences of very rapid change of level come from many parts of the Pacific shore, as in California, South America, and New Zealand), to introduce an inertia component acting eastwardly, which might at some period wholly or partly countervail the westward thrust and permit a maximum sinking of the sea-bottom. As continued cooling and renewed sinking reintroduced the thrust toward the land, it would be a thrust at maximum depth, and it might be kept steadily below the mountain-making intensity, and so act continuously as an epeirogenic force tending toward the increased elevation of the tetrahedral continent. Now, the tidal stresses, although small forces, would, operating year in and year out, like earthquake vibrations, acting irregularly, conspire with and to some extent give direction to the mountain-making forces along the American shore. On the other hand, they might on the Asiatic side aid in the transmission of the deeper seated forces, enormously great, but enormously slow, through wholly unexpected distances, and promote their efficiency as epeirogenic forces to dome up slightly the mass of Asia.

And this doming up in conjunction with the deep, offshore sea-bottom may have permitted the flow of the land-masses eastward to form the festoons of the Asiatic coast which have certainly flowed outward, coinciding with the southern sinking in the equatorial belt and the southward flow of the main Asiatic chains already described. This may avoid the necessity of adopting the marvelous suggestion of Suess—and a suggestion of Suess must be carefully considered even if it be marvelous—that, as the ice flowed from Canada to Cincinnati, the earth-masses have flowed from the Stony Tunguska across the broad reaches that later sank to be the Pacific toward the magnetic north pole in Boothia Felix, following and perhaps causing the lines of magnetic declination.*

In "Das Antliz der Erde" Suess, without asking the question why, announces the fundamental distinction between the Atlantic and Pacific coast types. He pictures the mountain chains around the whole Pacific moving toward that ocean, while around the Atlantic and Indian oceans the structures break off at the water. I had expected that his promised fourth volume would be an expansion of Mr Osmond Fisher's brilliant chapter explaining the Pacific as the scar where the moon was torn off, on Darwin's hypothesis; the Atlantic and Indian oceans as the fissures left as Australia and the Americas floated out toward the chasm, and the mountain chains about the Pacific as the last inflowing of earth matter to heal the scar, as wood grows in around a pruned branch.† The above suggestion of Suess involves a different but equally remarkable hypothesis.

PRINZ'S TORSION MAP AND DARWIN'S LINES OF WRINKLING

We must examine Prinz's interesting torsion map ‡ (figure 7) in connection with the tetrahedral ideas. We can not at first avoid the criticism that the most remarkable torsion line on the globe, the east Asiatic coast, is ignored entirely, and emphasis put on the unimportant chain of the Ladrones instead.

In the second place, we consider the curved band representing the Mediterranean zone to be the equator, all the curved bands above and below become parallels of latitude, and are thus brought into intelligible relation to the motion of the earth; and most of the oblique lines are then brought into the position of meridians and the apparent obliquity in the main disappears.

Moreover, if we redraw the map and emphasize all the northeast and southeast lines, as is done in the original for the supposed torsion lines, it becomes almost as good a map to illustrate Darwin's hypothesis of a tidal equatorial drift of the earth crust moving westwardly more rapidly at the equator than in middle latitudes.§

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*See appendix to this paper 96 for a reprint of Suess' article.

†Physics of the Earth's Crust, 1889, p. 336.

‡Sur les similitudes que présentent les cartes terrestres et planétaire (Torsion apparent des planètes par W. Prinz). Ann. de l'observatoire royal de Bruxelles, 1891, p. 304. See also Dana's Manual, p. 395.

§Loc. cit., p. 85.

Indeed, I have tried to explain the great equatorial notch in the Atlantic coastline of the Americas and the similar one in the Pacific coastline of the Asia-Australia mass, which prevents them taking the condensed tetrahedral shape of Eur-Africa, and the great elongation of the continents meridionally as a distant echo of this force.

The series of oblique and curved feature lines in Mars and less distinctly in Jupiter and Venus, with the probability that these planets may still be plastic at or near the surface, renders it possible that the similar lines on the earth may have had a similar origin. It must be borne in mind, however, that the mountain chains and great depressions which are among the important features here considered are of much later date, a few Paleozoic, the most and most important Tertiary.

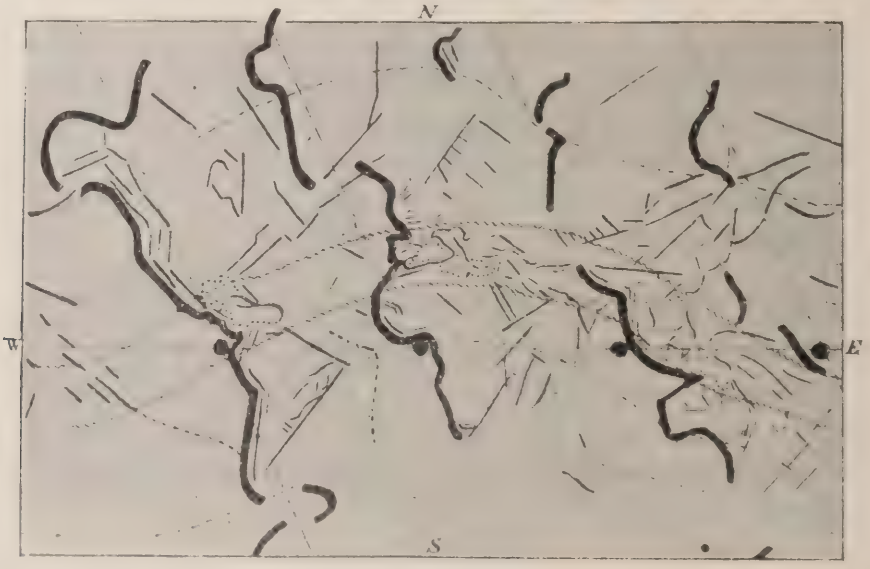

Figure 7.—*Prinz's Map of main Structure Lines on the Earth.*

Showing the indications of torsion.

I should search for remains of direct tidal wrinkles or fluidal structures in pre-Cambrian rocks, and the structures in all these areas should be studied for this purpose. It is quite generally true that the prevailing strikes in Archean beds are to the northeast north of the equator and southeast south of the equator. Von Richthofen cites the prevailing northwest strike in Shantung in China and northeastwardly into Corea as an exception to the rule, but there is even here a second pre-Cambrian folding present with northeast-southwest strikes.*

The purpose of this section is to show that the cause adduced by Darwin, conjoined with the cause which has produced the Mediterranean's, may explain the constriction of the continents, especially Asia-Australia and the Americas. These causes have been antagonistic to the realization of the tetrahedral form.

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* Von Richthofen: China, vol. ii, pp. 220, 233–236, 244 (1882).

RÉSUMÉ

The law of least action demands that the earth shall shrink into a tetrahedral form, with three continents tapering south, three oceans tapering north, a polar continent opposing a polar ocean—an earth whereon land shall be antipodal to water. The northern continents, raised into a circle of larger radius, may lag to west; the southern oceans, sunk into a circle of lesser radius, tend to advance east. By this Green explains the eastward shift of the southern continents. The foundering of land on the east and its elevation on the west of the northern continents explains most of this apparent displacement.

The strain dependent on internal tides has produced a zone of weakness in an ecliptic plane passing through the Mediterraneans. The torsion caused by the tetrahedral deformation has, according to Green, used this plane of weakness as a plane of twinning rotation along which the above shifts have taken place and along which the Mediterranean depression, mountain-making, and vulcanism have occurred.

An alternate speculation suggests that the ecliptic zone of fracture was, when formed, the equatorial zone and more oblate than now, and that by decreasing rotation and consequent sinking of the equatorial ring the deep depressions of the intercontinental seas were formed, and the mountain chains were made by sliding northward from the more resistant central Archean masses of the ring, except in Asia, where the mountain chains flowed in the southern direction because the equatorial ring was deeply sunk along this oceanic portion and the tetrahedral protaxis exceptionally raised in this great continent. As tidal friction caused decrease of the equatorial ring, escape of heat caused increase of the tetrahedral elevations and brought the pole to its present position.

It is of fanciful interest that in the magnificent pendulum swing represented by Crooke's spiral arrangement of the elements according to Mendelejef's law*—the ideal elemental section of the earth—the first culmination of the oscillation is in the tetrahedral carbon atom, the foundation of life; the second culmination is in the tetrahedral silicon atom, the center of the architecture of the crust of the earth—two models in microcosm of the earth itself. *Natura maxima in minimis.* The diamond, the perfect mineral coming out of the sky in the meteorite, presents again the most perfect model in the rounded faced hexatetrahedron of the form toward which the earth has imperfectly striven.

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* Chemical News, vol. lxxviii, July 15, 1898.

One is attracted by the comparison of the Mediterranean zone of torsion to a plane of twinning, as if the earth were a great hemitrope, and we may recall that Dana compared the northeast and northwest structure lines of the earth to crystalline cleavage.

Some things are very interesting, even if they are not true.

APPENDIX

Asymmetry of the Northern Hemisphere

BY E. SUESS*

During the last decade much new information has been gathered concerning the structure and distribution of the great folded mountain chains of the earth. While before this a synthesis of such information could have been ventured upon at best for single large areas, as, for example, Europe, it is today possible to recognize, at least in their principal traits, the mutual relations of the mountain chains around the whole earth.

The following lines contain the essential result of such an attempt, which includes the whole northern hemisphere. The quantity of the material employed is, however, so considerable that I must wholly abstain from giving here the proofs of the conclusions. This and the presentation of all particulars are withheld for another occasion.

I have felt compelled, at least in the first part of this article, to omit mention of any one of the many observers to whom I am indebted for instruction and to whom, if these comparative studies be found to have value, the merit alone belongs; for on one side stands the labor, the privation, often the danger, and almost always the giving up of the best years of one's life, and on the other only the gathering of the fruits.

I.

From the present position of the observations, so far as I have been able to master them, the following distribution of the axial lines (Leitlinien = guide lines = axial lines of the mountain chains) seems to result:

1. The peninsula Kanin, with the Timan mountains; Nova Zembla and Waigatsch; the Ural, with the Mugodja, form a natural group of

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*Sitz. Ber. k. Akad. d. Wiss. in Wien, Bd. cvii, Ab. 1, Apr., 1898.

NOTE.—I have translated, and by the kind permission of the author reprint here, the interesting article several times referred to in the preceding pages. It is an interesting indication that these thoughts are "in the air" that the part of my paper concerning the mountains of Europe and Asia was written before I had knowledge of this paper, and that a large share of the paper was written before I came on the lecture of Doctor Gregory, which I have used freely, while the interesting life of Green and abstract of his theory, by Professor Hitchcock (American Geologist, vol. xxv, 1900, page 1), I received, by the kindness of its author, since this paper was read.—B. K. EMERSON.

mountain chains whose most southern visible point is represented by the isolated outcrops of ancient rocks between the Caspian and the Aral, in 46° 30′, on the river Tschegan.

The Ural mountain chains are followed in western Siberia by a broad zone of folds which strike northeast. One of these chains causes the bend of the Ischim. They extend across the Kirgis steppe toward Bajan Aul and Karkaralinsk, disappear beneath the plains, and appear again by Kolywan. Thence they extend farther northeast, cross the Ob and the Tom obliquely, and abut against the Salair chain and coal basin of Kusnetzk, and reach the Alatau of Kusnetzk. We name them the Kirgis folds.

The mutual relations of the Ural and the Kirgis folds are not clearly recognizable. One sees, however, that the two combined form the most important part of the boundary of the west Siberian plain—that is, the region of the Ob. In the extreme north of Siberia the traces of a little known chain extend right across the Taimyr and reach the Arctic in cape Tscheljuskin. This is the Tamyr chain (Bogen).

A still larger chain begins with east-west strike at the mouth of the Olenek. It goes straight through the delta of the Lena, turns southeast, under the name Chara Ulach forms the Werchojan mountains, and finds its continuation in the range north of the Ochota, generally called North Stanowoj on our maps.

The chain completes a new bend, which is like that between the Lena delta and Chara Ulach. Its principal branch reaches in this way the watershed of the Anadyr, the cape of the Tschuktschis, and the Saint Lawrence island. This is the Werchojan chain.

No connection with the American side is known.[*]

The breaking up of the ranges (die Zertrümmerung des Geberges) in Bering sea and the covering of western Alaska by Tertiary sediments make the comparison difficult. In the interior of Alaska, however, conditions of a wholly different kind appear. A great gneiss chain extends nearly from west to east about in the direction of the Tanana river, north and south of the sixty-fourth parallel and in the chord of the arc of the Yukon. It turns then east-southeast and southeast, and forms the watershed between the Pelly and the Lewes, follows the course of the Findlay, and is considered as the continuation, perhaps locally interrupted, of the Caribou region and the Golden ranges in British Columbia. Associated with this chain, especially along its northern border, are ancient sediments altered by pressure, which are the source of the gold of Alaska.

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[*] Professor Suess tells me that "a paper since published by Baron E. Toll, of Dorpat, perhaps brings the clue to the difficult question of the relation of the Alaskan Sierra to the Siberian mountains." In this paper (Otsherk Geologij Novo-Siberikij Ostrowonj. Mem. Acad. Saint Petersburg, 1899, viii ser., vol. ix, no. 1) Baron Toll gives a geological sketch map of the western part of the Merchojana curved chain, and pronounces his conviction that "the structure of this mountain chain is *concave*—that is, that the rocks are folded against the interior of the curve."

Professor Suess is of opinion that "in this case these mountains might indeed be regarded as the true continuation of the Alaskan Sierra, both being equally folded toward the north, and the same chain would then appear continued across Bering sea along the right side of the lower Lena to the mouth of the Olenek, gradually diminishing toward this point."

My own observations would agree better with the earlier conclusion of Professor Suess in the body of the paper.

Touching at Plover bay and coasting along to Indian point, on the mainland of Siberia, opposite Saint Lawrence island, I saw only mountains of granitoid rocks of light and dark color, and found boulders of the same and of crystalline limestone on Saint Lawrence island.

At Port Clarence, on the Alaskan mainland opposite to the northeast and almost in Bering strait, I found only the cleaved fossiliferous slates of the Yakutat formation, probably of Triassic age, while the gneissoid axis of the Alaskan Sierra seems to trend southwest from the Tanana hills to meet the sea far south of the delta of the Yukon. (B. K. E.)

This is followed, far to the northeast and east, by the zone of great fault-blocks, which is here called the Rocky mountains.

Its outer border extends from the mouth of the Mackenzie down to Wyoming. In other words, there is in British Columbia an extensive one-sided chain, folded and overthrust toward the east, whose western part is formed by the Golden ranges (Selkirk, etcetera). This chain, which in British Columbia strikes north-northwest, bends around so that in middle Alaska it strikes east-west and is there folded toward the north. On the west the ancient granite and gneiss do not reach the lower Yukon, but the gold-bearing rocks outcrop in low hills in about 65 degrees north on the lower course of the river.

This range is therefore wholly foreign to the Werchojan range. On the other hand, there appears on the west coast of British Columbia a very thick belt of granite, often accompanied on its west side by volcanic occurrences. It forms the Coast ranges which pass in a course to the north of Mount Saint Elias, and in all probability meets in union (in Schaarung) with the curve of the Aleutians.

The curve of the Aleutians is the last toward the east which shows the typical form of the inland curve. The Commanders islands differ somewhat in their composition from the Aleutian, so that the contact with Kamschatka is doubtful. The Tertiary beds, partially marine, which are extensively developed on the lower Yukon and in the Aleutians, probably also form the Karagin island. They are also met in the gulf of Penschin and perhaps underlie the tundra which separates Kamschatka from the Werchojan curve.

All the above named mountain chains from the Kanin peninsula on to Bering sea, stand in contrast to the Eur-Asiatic folds, as wholly foreign to them or at least as not fitting into the general plan which controls them. All are folded toward the west, south, or east and open toward the pole. They have no equivalents in North America except, perhaps, the Coast ranges. Horizontal Paleozoic tablelands extend over the Arctic archipelago of North America.

2. The Baikal and the region of the Angara are surrounded by a great horseshoe-shaped zone of ancient faulted rocks. It reaches northeast to the junction of the great Paton and the Lena (60 degrees northeast), and here the folds strike southwest. On the other side they can be followed northwest to a point below the entrance of the stony Tunguska in the Jenissei. Here the strike is southeast, and the same strike has been followed along the Jenissei in single occurrences even as far as 68 degrees north latitude.

This great amphitheater is also open toward the north. It surrounds the north Siberian plain. The Lena flows along its border in flat lying Paleozoic strata which in places extend down to the Cambrian. The amphitheater is for the most part, at least, older than Cambrian.

A fault which runs along the right bank of the Jenissei from the region north of Krasnojarsk to near the mouth of the Stony Tunguska bounds these rocks on the west. A second fault, probably pre-Cambrian, lies in the interior of the amphitheater not far west of the west shore of lake Baikal. Eastwardly the old rocks extend to the Jablonnoi, which is a fault or flexure and not a folded chain.

These three lines of sinking, on the Jenissei, west of Baikal, and on the Jablonnoi, give this region of ancient rocks more or less the character of a horst. On the south, however, one can not separate it from folded chains in which fossiliferous Paleozoic sediments find place. It is especially clear that east Sajan must be wholly separated from west Sajan, and that the latter continues west, retaining its original direction, crosses the Jenissei above Krasnojarsk, and finally ends west of the same.

Ergik-targak is the name of the east Sajan, and we will use this name for the whole folded chain extending beyond Krasnojarsk. It appears not to be sharply separated from the amphitheater of ancient rocks in an orographic sense, although near Krasnojarsk lower Devonian beds are involved in its folds.

The old rocks between the fault on the Jenissei and Jablonnoi by Tschita form the center of all that great series of curved chains which, with manifold deviations and confusions, but yet on the whole under homologous arrangement, reach from Saghalin to Java and on to the Himalaya and the Persian gulf. While they form the middle, it is not yet asserted that they form the point of origin of these chains. As far as we can gather from single data, there appears to be, toward the middle of this great central mass, rather a tendency toward a sort of backward folding of the rocks toward this center, which farther outward is gradually replaced by an outward folding, which finally leads to the overfaulted sheets (Deckschollen) in the inner chains of the Himalaya and to the great overthrusts of its southern border.

The structure of the Eur-Asiatic folds, in so far as its Asiatic portion is concerned, depends therefore on a plan which was marked out in pre-Cambrian time, whose development, however, extends in many parts up into the later Tertiary and is probably not yet concluded. Its most essential source of confusion comes from the intercalation of the ancient Sinian table and in a meridional disturbance near Sailughuem.

3. The branches of the Tian-shan abut at first on the transversely striking Kirgis folds. North of Karkaralinsk the two opposing directions join, and not until a point is reached south of the southernmost prolongation of the Ural folds do these branches obtain free development and extend westward in continuity with the folded chains of central Europe. The change to northward of the folding force characteristic of middle and western Europe occurs at the same time. This phenomenon is also of great age, as the pre-Devonian Caledonian folds prove. The arrangement of the middle European folds, however, from the gneisses of the Hebrides on to the border of the Alps, shows an indubitable shrinking of the folding into a narrower space surrounded by horsts, though made less striking by posthumous (that is, later) motions.

The succession of the Hebridian, Caledonian, Armorican-Variscan and Alpine folds is in general uniform, and is at the same time, to a certain degree, the opposite of the order in Asia, where not only at many places in the interior, but also almost all around the periphery new folds appear, as if there were still a tendency toward their extension. For this reason Europe appears in still higher degree as an appendage or lateral extension of eastern Eurasia.

In relation to the Norwegian mountain region, the opinions of local investigators are still so divergent that reserve is necessary for this region.

It must be further remarked that along the lines of junction that extend from the Thian-shan, and especially from the Hindoo Koosh to the European mountains, recent movements reaching high up into the Tertiary are common, and the question is not yet answered whether also at the time of the Caledonian folds a connection with Asia existed in the same region south of the Urals.

It is plain, at all events, that the lithologic character of the Caledonian outcrops of gneiss is related to that of the Hebridian foreland. Further, that the older masses that emerge from the folds of the Ardennes possess the characteristics of the Caledonian discordance, and that in the same way in the zone of Mont Blanc and in the Carinthian Alps the Variscan type is visible beneath the Alpine folds.

The relations of the European mountain chains to the Atlantic ocean are as follows:

a. The chain of the western Mediterranean bends back by Gibraltar, so that a continuation of the same into the ocean can not be assumed. Such continuation would be only supposable for the great Atlas north of Wady Draa.

b. The folds which form the Spanish Meseta also betray, in the Asturian basin, that they are bent back on themselves; here also a continuation for a long distance west can not be assumed.

c. In relation to the possible continuation of the Pyrenees I do not venture to express a suspicion, in spite of new and excellent investigations.

d. The Armorican folds from La Rochelle to near the Shannon, wholly in contrast to Gibraltar and the Meseta, run out into the sea as rias coasts in such a way that their former continuation into the region which is today covered by the ocean is in the highest degree probable. In fact, the whole visible Armorican region is only the east end of a great and broad curve, convex toward the north. It occurred for the most part between middle and upper Carboniferous, but has since experienced later ("posthumous") movements. It consists of several curved folds, one behind the other.

e. The pre-Devonian Caledonian folds, which strike southwest, have such a position in the north and west of Ireland that their outer border may meet the Armorican lines not very far west of the mouth of the Shannon, perhaps to disappear under them, as the more easterly folds of the same chain disappear, or, as in Moravia, the Variscan folds sink under those of the Carpathians.

f. Lewis and the western Hebrides, together with a small part of the peninsula of western Scotland, form the foreland of the Caledonian folds, and are simply the eastern border of a great Archean region which is now covered by the sea and from which the significant quantity of clastic sediments was derived which has caused the great thickness of the old Paleozoic deposits in Wales and bordering regions.

The Hebridian gneiss had certainly a greater western extension, as has often been asserted by leading British geologists.

From these facts the following tentative result is reached concerning the relation of Europe to America and concerning the character of the Atlantic region; that the coast tracts, *a* (Gibraltar) and *b* (Meseta, Asturian folds) do not permit the assumption that their structure continues far westward; that *c* (Pyrenees) and *d* (Caledonian folds) are uncertain; that, on the other hand, *d* (Armorican folds) and *f* (Hebrides) appear to be the eastern ends or borders of regions which are covered by the ocean.

This series of surmises leads to the conclusion that under the north Atlantic there is on the north a broad Archean region and south of the same a curved chain folded toward the north, in which the Upper Carboniferous rests in discordance on older eroded folds.

4. It is a very remarkable fact that the east coast of North America actually corresponds to these surmises. There appear here, in fact, with the exception of some possible Caledonian tracts, only two tectonic elements which show the essential characteristics of *d* and *f*. They are separated by Belle Isle straits and the lower course of the Saint Lawrence river. To the north lies the broad Laurentian Archean mass—the Canadian shield—and probably extends broadly toward the pole beneath the horizontal Paleozoic sediments of the Arctic American archipelago; also extending across to Greenland. South of the same, in the rias coasts of Newfoundland, Nova Scotia, and New Brunswick, appears a region of folded rocks with discordant transgressing Upper Carboniferous, which is as plainly the western continuation of a great folded chain as in Europe the Armorican ridges are the east end of such a chain. The Appalachians extend southwest as the continuation of this chain. New observations teach us, however, that this chain, which is folded toward the northwest, does not end where it was supposed to, but makes a concave bend in the strike from southwest to west, and at the same time shows strong overthrusts. These overthrusts are directed toward the concavity of the curve, an occurrence which is nowhere known in Europe or Asia, at least in anything like so large a scale. The occurrences on the concave section of the curve extending from the Alps to the Carpathians near Vienna are too small for comparison.

The western-striking continuation of the Appalachians reaches the flat land of the Mississippi and disappears, but the new investigations in Arkansas, in Texas, and the bordering Indian Territory show that the continuation of the Appalachian folds appears again on the west side of the depression of the Mississippi in the Ouachita mountains, which extend nearly to the one hundredth meridian as a long tongue broken into many separate folds.

The contrast to the recognized arrangement of the curves in Eurasia appears still more clearly here, since the foreland is surrounded by the folds in a concave line. Nothing similar to this is seen in Europe or Asia.

The fact has been established in late years that the Sierra Madre, which consists of granite and Archean rocks, following the west coast of Mexico, continues across the gulf of Tehuantepec, and by a bend to the east passes over into the chain which extends across Guatemala to the Amatian gulf. The Sierra Madre has therefore a concave structure similar to the southern part of the Appalachians. This changes the descriptions we have formerly given of northern Central America. The whole Mexican gulf and the Cambrian area of Austin (Texas) find place between the two concave chains.

New questions arise now beside the old ones, concerning the wholly peculiar build of the Rocky mountains in the narrower sense (Colorado Front range, etcetera) and their backward bent ranges, concerning whose answer I should not now wish to venture a surmise. It is certain that north of these chains in the eastern part of the mountains in Wyoming movement and folding to the northeast occur, and north-northeast in Montana, in 45 to 46 degrees north latitude, repeated overthrusts to the east. In the same way the Cordillera in Canada, as already noted, is remarkable for its extraordinary overthrusts to the east. The Laurentian mass is thus bordered by chains on the east, south, and west, and the folding motion is everywhere directed inwardly—that is, to the west, north, and east.

Now one understands better the fact, often mentioned before, that in Asia the folding is to east, south, and west; in Europe to east, north, and west. It is because the European chains form the transition from the Asiatic to the American structure.

II.

While I again reserve for another place the thankful mention of the observers who have been my teachers and the enumeration of the details, especially of the structure of Asia, some of the deductions which flow from the observations may be here mentioned.

First, the very apparent contrast between Eurasia and North America. The first region shows an outflow of the folds, or a motion outwardly, and the second, with possible exception of the Coast ranges, an inflow or motion inwardly.

Strictly speaking, there is nothing new in this. Many of the most important students of Asia, like Semenow, F. v. Richthofen, Griesbach, Edm. Naumann, have each, according to his standpoint, recognized at times the step-like sinking of the whole of eastern Asia on Jablonnoi, on the great Kingan, and on the coastlines, at times a southward motion of the whole mass, or an elevated calotte with peripheral faults; but the conception of a great unity of structure always appears, and often also that of a more or less concentric arrangement, or a mass-motion outwardly.

In North America the opposite ideas have developed. Dana, Leconte, Dutton, and other important students have espoused different modifications of the theory that mountain chains are formed by the sinking of the oceans—that is, that they have, as if by a force from without, been joined to or thrust against the old preexistent nucleus of stable land (in this case the Laurentian mass). The theory of isostacy has developed itself from this position, namely, the view that the heavier loading of the surface by sediments produces sinking and a complementary elevation in some other place.

In these contrasts of the general conceptions of the nature of the continents and their relation to the seas which have arisen from the observation of nature, on the one hand in Asia and on the other in America, is reflected a complete contrast of structure; and since the American views are based on the particular build of the North American continent they have not received the same degree of recognition in Europe.

But this is not the only contrast which can be gathered from former writings. As early as 1887, also, Marcel Bertrand drew a line of junction from the Armorican folds right across the ocean to Newfoundland.* This means, in other words, that these chains which were folded up before the close of the Carboniferous are continued westerly, either directly or by the junction of independent ranges now sunk beneath the Atlantic; appear again with similar structure on the northeast coast of America, then make a concave bend and end at last in the Ouachita mountains. It follows further from this that the north Atlantic is younger than this range. This agrees with other observations. It is more difficult to understand the role of the much older Pacific ocean. One sees in Asia chain behind chain. Often two or more chains joining at acute angles are spanned by a single larger curve, as in Asia Minor and in Iran. The Burman curve becomes very large.

One can imagine that the great curves, finally meeting a hindrance, transformed themselves into long lines that at last became concave like the Appalachians and the Sierra Madre. Such an idea assumes that the original outlining of the west American Cordillera is older than the Pacific; that the northern coast ranges with their long granite chains, which do not reach back before the Mesozoic time, and with their very late movements, are a later interposition, and that the Cretaceous overthrusts of the northeast Cordillera are caused by later ("posthumous") movements.

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* Bull. Soc. Geol., 2d ser., vol. xv, p. 442.

M Marcel Bertrand goes still further and unites the Green mountains with the Caledonian zone. They represent, in fact, folds that are older than the Armorican discordance.

The further consideration of this question may be held in reserve until the southern hemisphere can be brought into consideration. This much is already clearly recognizable: That the contrast between the structure of the northern part of America and of eastern Asia betrays a lateral asymmetry of this hemisphere reaching back into the Cambrian time. We should not say an original asymmetry, for the Laurentian rocks were also folded, and that in pre-Cambrian time. The direction of these folds seems to have been a wholly independent one, but their strike is known in only a relatively small part of the broad region.

One is inclined to suspect that the formation of the curved chains in Asia, open toward the north, stands in some connection or other with the outflow of superfluous earth-mass from the pole—that is, with a flattening of the same. One can also recognize a certain resemblance between these curved chains and the course of the moraines, and also the forms of the glacier lobes which Chamberlin draws across the east of the United States. We shall have at a later time to investigate whether curved chains directed toward the north are present in the southern hemisphere, but already the influence of the Laurentian mass (with Greenland and a portion of the polar land) appears plainly enough.

More striking than any connection with the pole of rotation appears a certain relation to the magnetic pole which lies in the midst of the zone of inflow. In fact, the distribution of the guiding lines (Leitlinien = axial lines of the mountain chains) seems to favor a connection between the mountain-forming force and terrestrial magnetism, as suspected by Edm. Naumann and other investigators, and that in the sense that the latter is the result of the former, a result influenced also by other causes.

It now appears also that the separation of the movements into tangential (folding) and vertical (sinking) motions must be much more sharply held than before. The relation of the Atlantic ocean, which is younger than those chains, to these latter makes this clear. The acute comparison drawn a long time ago, especially by Reyer, between mountain folding and fluid motion was justly objected to because a fall for such a fluid motion was not recognizable. As soon as we are able to oversee the whole hemisphere and distinguish a region of outflow and one of inflow, this question also gains a new importance.

In relation to the often-discussed question of the permanence of the continents and the oceans, we recognize the following: individual folded chains are dislocated and broken up in horsts, and later folds heap themselves up against the horsts. At the same time the location of the region of outflow and the region of inflow, as well as the arrangement of the superficial tensions which find expression in the guide lines of the folds, has remained the same in its principal features throughout the northern hemisphere since the Cambrian time—that is, since the existence of the oldest known traces of organic life to the present day. A similar degree of permanence, however, does not belong to the oceans. During this time new oceans have been formed by sinking, whose succession in time expresses itself in the transgressions. Other oceans have disappeared, partly as a result of the new depressions themselves and partly by the heaping up of new folded chains according to the old plan.

So do the boundaries of the continents and the seas change, despite the constancy of the plan of the axial lines.

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UPPER AND LOWER HURONIAN IN ONTARIO

BY ARTHUR P. COLEMAN

(Read before the Society December 28, 1899)

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INTRODUCTION

The original Huronian area, as mapped by Logan and his assistant, Murray, lies within the province of Ontario, which contains also its northeastern extension toward lake Temiscaming and several other large and important tracts which have been mapped with more or less certainty as Huronian by Canadian geologists since Logan's time. As these rocks contain the most promising ore deposits of the province, they naturally attract much attention from prospectors and geologists, and the problems connected with their formation and relationships have an economic as well as a purely scientific interest. The question as to what areas are really Huronian, and as to the relative age of the different areas mapped as Huronian, differing as they often do in striking ways from the rocks of the original region, is one requiring solution if the pre-Cambrian geology of the province is to be placed on an assured basis. During the past summer an examination of the newly discovered iron region in the Huronian district northeast of lake Superior for the Bureau of Mines of Ontario has provided a set of facts which appear to throw new light on the subject.

FERRIFEROUS SANDSTONES, CHERTS, AND JASPERS

For a number of years iron ore has been known to exist at little Gros Cap, on Michipicoton bay, but the finding of important deposits of high-grade brown hematite north of Wawa lake, some miles inland, has aroused fresh interest in the region, and has resulted in the tracing up for many miles of a band of silicious rock interleaved with thin sheets of iron ore, in many respects much like the famous iron ranges of Michigan and Minnesota. The rock has generally the aspect of a sandstone, but thin sections prove that it is not an ordinary sandstone, in spite of the fact that many parts of it crumble to fine grains under the fingers; for the grains of quartz have polygonal forms that meet in planes, but are only loosely, if at all, cemented. The grains are often six-sided, and in thick sections show a rough dodecahedral shape, the result probably of growth outward from numerous nearly equidistant centers until the grains met, just as spheres crushed together tend to take on a dodecahedral form.*

The usual variety resembling sandstone sometimes passes into a rock like chert or in other cases jasper, and occasionally takes the appearance of quartzite. In many parts of the range the interbanded sandstone and magnetite or hematite are more or less brecciated, and have undoubtedly undergone great folding and crushing. The band now stands nearly vertical in most regions to which it has been followed.

This band of rock is usually thin, not more than a few hundred yards in width, and there are numerous interruptions in its outcrop, due probably to weathering, for the sandstone variety is so fragile that in river valleys it has been cut down faster than other rocks and is often lost to sight under the thick drift deposits of the region. This probably accounts for the fact that it was overlooked until last summer, since the region is without roads and hitherto had been explored almost entirely with canoes.

The cherty and jaspery varieties, however, stand weathering excellently and form ranges of hills easily followed. The ore bodies found associated with the sandstone are of considerable variety, magnetite of low grade being commonest, though soft red hematite and hard and soft limonite occur also, the latter, in the case of the Helen mine, amounting to hundreds of thousands of tons of exceptionally pure ore. None of the deposits have yet been sufficiently explored to determine their extent.

It is almost certain that this band of silicious rock charged with iron ore is of sedimentary origin, although perhaps not clastic, but rather deposited chemically.

EXTENT OF THE IRON RANGE

The band of sandstones and jaspers containing iron ores, though so narrow, has already been followed for more than 50 miles, of course with interruptions where covered with drift. Starting at little Gros Cap, it runs about 20 miles to the northeast, then bending to the north and west it takes a westerly direction for more than 30 miles. How much farther it runs in that direction is unknown, prospecting having stopped for the winter a few miles west of Dog river. The same association of silicious rock and iron ore is found more than 70 miles farther west, near Pic river, though it is not supposed that the range will be traced continuously to that point, for a tract of Laurentian is mapped as lying between. Whether these rocks should be looked on as a continuation of the Vermilion iron range north of lake Superior in western Ontario and Minnesota and of the Penokee and Marquette ranges to the south of the lake is not certain at present. Iron miners from Minnesota consider it the same formation as the Vermilion range, and there seems no reason to doubt that it was formed under very similar conditions and shows many points of resemblance to that range.

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*Cf. Irving and Van Hise, Penokee Iron Bearing Series, U. S. Geol. Sur., monograph xix, p. 133, etcetera, where the grains seems to be described as crystals rather than unoriented polyhedra.

Sandstones of the same peculiar type occur at Little Turtle lake, east of Rainy lake, and near Fort Frances, on Rainy river, as well as at the Scramble gold mine, near Rat Portage, on lake of the Woods. Thin sections of these rocks show the same polygonal shapes of the grains of quartz, and more or less iron ore is associated with specimens from each locality. It is very probable, then, that the same horizon exists at points far to the west of lake Superior.

Turning toward the east, specimens very like the jaspery varieties of the Michipicoton iron range are found interbedded with iron ores near lakes Wahnapitae and Temagami, between Sudbury and the Ottawa river. If, as seems probable, these jaspers are the equivalents of the western Huronian sandstones, we have a definite horizon traceable from point to point across the whole northern end of the province, a distance of more than 600 miles. It is not suggested, of course, that these iron-bearing sandstones and jaspers will be traced for this distance as a continuous band, for the Huronian areas are separated at several points by tracts of Laurentian; nevertheless, if the conclusions just advanced are correct, we have in these rocks a most valuable thread with which to unravel the much disturbed and complicated series of the Huronian in Ontario.

THE DORÉ CONGLOMERATE

Less than 2 miles north of the iron-bearing sandstone of Little Gros cap there is a remarkable exposure of schist (or slate) conglomerate, examined many years ago at the mouth of Doré river by Sir William Logan, who evidently considered it a typical example of the Huronian, since he has described it somewhat fully in his general account of that formation.* Among other pebbles in the conglomerate he refers to some of a chert-like stone. While studying this outcrop, which is well exposed on the wave-beaten shore at the mouth of the Doré, and also on islands to the south, the present writer found many pebbles, not only of the cherty iron-bearing rocks, but also of the pulverulent sandstones. Pebbles and boulders of all sizes, beautifully rounded and of a considerable variety of rocks—none, however, of typical Laurentian gneiss—are to be seen here in a section dipping from 70 degrees to verticality, and with a measured thickness of more than a third of a mile.† The conglomerate has been traced by Professor Willmott and the writer about 17 miles from east to west and probably extended still farther, since small outcrops of conglomerate are found to the east. Belts of conglomerate are seen also within 2 or 3 miles of other parts of the sandstone range, but no search has yet been made for pebbles of sandstone or jasper. It is evident that the Doré conglomerate marks a very important break in the Huronian of the region, and it is probable that the other conglomerates referred to are to be looked on as of the same age. The lack of Laurentian pebbles shows that they are not basal conglomerates of the Huronian resting on a Laurentian floor, and the chert and sandstone pebbles prove that they are more recent than the iron-bearing series.

Conglomerates near Rainy Lake

A very extensive series of schist conglomerates has been mapped by Lawson on Shoal lake east of Rainy lake, and was thought by him to be a basal conglomerate of the Keewatin above the Couchiching.‡ The same region has been examined by Winchell and Grant, who report that black and red jaspers occur in it as pebbles,§ and by the present writer, who found numerous pebbles of pulverulent sandstone, as well as of cherty materials, along with the more common felsite and porphyry pebbles.‖ This conglomerate has been traced for about 15 miles from southwest to northeast, and probably has a thickness little short of a mile. That it represents a very profound break in the Keewatin series is shown by the fact that among its boulders are some of anorthosite evidently derived from an adjoining mass of that rock. The anorthosite itself is proved to have erupted through rocks apparently belonging to the lower Keewatin, since it carried off in its eruption fragments of chloritic and sericitic schist exactly like certain Keewatin rocks of the region. The conglomerate was formed, then, at a far later time than the underlying Keewatin schists, since they must have been solid rocks before the eruption of anorthosite, and this very coarse grained plutonic rock must have had time to cool, doubtless at a great depth, and to be deeply eroded before pebbles of it could have been rolled on a seashore and incorporated in a rock belonging to the upper part of the series.* This conglomerate is about three miles south of Little Turtle lake, near which iron-bearing sandstone has been found.

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* Geol. Can., 1863, p. 54.

† Ont. Bur. Mines, vol. viii, second part, 1899, pp. 165–167.

‡ Geol. Sur. Can., 1887–'88, p. 82 F.

§ Geol. Sur. Minn., 23d Ann. Rep., 1894, p. 66.

‖ Ont. Bur. Mines, 1895, p. 97.

Lawson maps conglomerates of a similar kind on the Minnesota side of Rainy lake, where the river of the same name flows out, and mentions saccharoidal quartz pebbles as occurring in them along with various other kinds of rock.† He also describes a conglomerate at the west end of Schist lake, containing pebbles composed of quartz "in a very fine mosaic aggregate, partly chalcedonic." ‡ Probably these pebbles are of the same character as the iron-bearing sandstone found by myself a mile east of Fort Frances, on Rainy river. Another important belt of conglomerate containing sandstone and black quartzitic pebbles occurs near Mosher bay, at the east end of Upper Manitou lake, about 25 miles north of Shoal lake.§ From the facts just mentioned it will be seen that conglomerates with sandstone pebbles are widely distributed in the Rainy Lake region.

Schist conglomerate occurs also at Rat portage, a short distance southeast of the sandstone band found at the Scramble gold mine, but up to the present no pebbles of sandstone have been observed in it, though it is probably of the same age as the conglomerates of the Rainy Lake region, 80 or 100 miles to the southeast.

THE JASPERS OF THE EASTERN HURONIAN

Turning now to the eastern portion of the province, which includes the typical Huronian north of lake Huron and its extension to lake Temiscaming, no undoubted sandstones have been found, though a silicious rock with narrow bands of magnetite, probably the equivalent of the Michipicoton rock, occurs near Batchawana bay, at the southeast end of lake Superior. I am indebted to Mr J. A. Holmes, State Geologist of North Carolina, for this information, which he obtained while examining an iron deposit nine miles inland. Jasper banded with hematite and magnetite is known to occur at two points in the northeastern part of the area, having exactly the same appearance in hand specimens as the jaspery rocks of the Michipicoton iron range. I have not visited the points myself, but the specimens have been brought in by prospectors. How extensive these jasper bands are is not yet known.

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* Jour. Geol., vol. iv, no. 8, 1896, p. 911.

† Geol. Sur. Can., 1887-'88, p. 82 F.

‡ Ibid., p. 84 F.

§ Ont. Bur. Mines, 1897, p. 123.

We do know, however, that jasper conglomerates form a very striking part of the quartzitic rocks of the typical Huronian, and that pebbles of jasper are met with more or less commonly in conglomerates as far east as lake Temiscaming itself.*

Source of Jasper Pebbles of the Huronian

The source of these pebbles in the typical region on the shore of lake Huron has not yet been explained, since no bands of jasper have been reported in the neighborhood. Possibly they are concealed beneath the extensive lacustrine deposits of the region or are sunk below the waters of lake Superior or lake Huron. From the widespread and abundant occurrence of these jasper pebbles we may infer a source of considerable extent. They can hardly have been obtained from the underlying Laurentian, for jasper has never been reported from the Canadian Laurentian; and since the jasper pebbles are in many cases distinctly stratified and are associated with black chert pebbles, we must suppose them to be of sedimentary origin, and so excluded from the Laurentian, employing that term in the usual sense of a complex of ancient eruptive rocks now more or less schistose.

It is true that ferruginous chert is reported by Irving and Van Hise from the Marquette region, associated with the Kitchi schist, which they include in the Basal complex, but those authors are of opinion that the small deposits referred to are in reality of vein formation, and therefore later in age than the schist which incloses them.†

One is tempted to ask if these cherty deposits are not more probably remnants of the lower Huronian nipped into the Laurentian. The green Kitchi schists themselves would probably be placed by Canadian geologists in the Keewatin or lower Huronian rather than in the Basal complex or Laurentian.

The most important Break in the Huronian

Van Hise, the Winchells, and other American geologists who have examined the typical Huronian area are of the opinion that a break occurs in the series between Logan's upper and lower slate conglomerates, just above the main band of limestone, and that this is probably the equivalent of the unconformity between the upper and lower iron bearing series of Michigan and Minnesota.* My own study of these rocks leads me to the conclusion that this break is not of great significance. There are pebbles of limestone in the upper slate conglomerate showing a certain interruption in the series, but the lower slate conglomerate (or graywacke conglomerate) is very like the upper one and is not appreciably more crystalline or schistose. Specimens from the basal conglomerate east of Thessalon can be perfectly matched by specimens from the upper conglomerate on Echo lake. It is much more probable that the real break is beneath the basal conglomerate near Thessalon. It is likely that some of the green schists found in the adjoining Laurentian are the equivalents of the lower Keewatin, west of lake Superior, and so represent the lower Huronian in the typical region.

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* Geol. Can., 1863, pp. 52 and 56.

† U. S. Geol. Sur., monograph xxviii, Marquette Iron Bearing Dist., pp. 186, 187.

Much stress has properly been laid on this basal conglomerate by Irving and Van Hise, and it will be well to discuss its bearing on the Huronian question.† If the lower part of the typical Huronian series corresponds to the Vermilion and other lower iron-bearing rocks of the states to the west and south of lake Superior, it should contain an equivalent for the characteristic jaspers interbedded with iron ore; but no such rock has been found by Murray in his careful work when mapping the region, nor by any later observers. On the other hand, jasper pebbles are found in greater or less numbers to the very bottom of the series, a few occurring in the basal conglomerate itself.‡ If it be admitted that the large numbers of jasper pebbles, often with a banding suggesting sedimentation, are derived from a widespread sedimentary rock, then sediments must have been formed on a large scale and have been consolidated and rolled into pebbles before the basal conglomerate was laid down. It is clear that this basal conglomerate is not the lowest rock in the Algonkian, as defined by Van Hise in his excellent correlation work, nor in the Huronian, as usually defined by Canadian geologists, but that a jasper bearing lower Algonkian or Huronian is to be looked for somewhere as a source of its pebbles.

On lake Temiscaming, at the northeastern end of the same great Huronian area, another basal conglomerate has been described by Barlow and Ferrier.§ The reasoning just given will apply to this conglomerate also, for a few months ago Mr Archibald Blue and the writer found jasper pebbles almost at the base of the Temiscaming conglomerate. In this instance, however, a piece of jasper with iron ore brought by a prospector from an outcrop near lake Temagami provides a reasonable source of the jasper pebbles, and proves that the lower Huronian is represented, to some extent at least, a few miles to the westward.

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* Van Hise, pre-Cambrian, p. 777; Alex. Winchell, Bull. Geol. Soc. Am., vol. iv, 1893, p. 344, and Am. Jour. Sci., vol. xlii, p. 317.

† Cf. Ont. Bur. Mines, 1899, part ii, p. 160, etcetera.

‡ Ibid., p. 162.

§ On the relations and structure of certain granites and associated arkose on Lake Temiscaming. British Assoc., Toronto, 1897.

CONCLUSIONS

Granting that the ferriferous sandstones, cherts, and jaspers described above belong to a definite horizon near the top of the lower Huronian (or Algonkian), and that the conglomerates often found near by containing sandstone, chert, or jasper pebbles represent also a definite horizon as basal conglomerates of the upper Huronian, some interesting conclusions follow.

In the first place, the gap between upper and lower Huronian is shown to be a very profound one. Basal conglomerates, often thousands of feet thick and found from point to point over a distance of more than 600 miles, indicate an erosive period of great extent and significance. In the next place, we have in these widespread rocks a means of correlating the often widely separated and very different looking rocks mapped as Huronian in Ontario. Doctor Lawson, in defining his Keewatin on the lake of the Woods and Rainy lake, came to the conclusion that the highly metamorphosed schists and eruptives of that region stood lower in the geological scale than the less altered quartzites, etcetera, of the typical Huronian as described by Logan. If the ground taken in this paper is correct, viz., that the Shoal Lake conglomerate is at the base of the upper Huronian and the ferriferous sandstones found at some points in the region belong to the lower Huronian, it is evident that at least a part of the Keewatin is of Huronian age. Whether the great beds of schist formed of pyroclastic materials and sheared eruptives mapped by Doctor Lawson are older than the lower Huronian, and so should retain the name Keewatin as a separate formation, need not be discussed here.

The resemblance between the iron-bearing rocks shown to exist in Ontario and the upper and lower iron-bearing series so carefully worked out in Minnesota and Michigan suggests that they are of the same age, and that the break between the upper and lower Huronian extends along the south side of lake Superior as well as the north, though it is too soon to state positively that this is the case. The detailed mapping of the Vermilion series of Minnesota to the boundary of Ontario, which Professor Van Hise informs me is about complete, will give an opportunity to trace with more certainty the relations of these two great areas of pre-Cambrian rocks.

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VOLCANICS OF NEPONSET VALLEY, MASSACHUSETTS

BY F. BASCOM

(Presented before the Society December 30, 1899)

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INTRODUCTION

While the igneous rocks of the Boston basin have been the subject of considerable investigation and discussion, the volcanics of the limited portion of the basin drained by the Neponset river have received little attention. No petrographic study has been made of these volcanics.

Recently Professor W. O. Crosby afforded the writer an opportunity to visit this district and to collect specimens, and further encouraged a more detailed study of the material collected.

The general geology of the region has been investigated by Professor Crosby and is quite aside from the purpose of this paper. A brief sketch of the results of the investigation,* so far as they have appeared, may not, however, be out of place.

STRUCTURE OF THE REGION

The prevailing rock is a conglomerate and the prevailing structure is anticlinal. Along the northern margin of the belt the conglomerate dips to the north under a slate, and along the southern margin the dips are to the south, and the conglomerate passes again under the slate. This structure is complicated by several sharp synclines and numerous faults.

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* Physical History of the Boston Basin, 1899. The Neponset Valley, p. 6.

In the western part of the valley erosion has uncovered the volcanics. The acid volcanics are the floor on which the conglomerate rests, while the basic volcanics occur as dikes and as flows interbedded with the conglomerate. There are three flows of non-porphyritic basic lava and one of porphyry.

Age of the Rocks

The age of the conglomerate is Carboniferous.

The acid volcanics must be pre-Carboniferous, while the basic igneous material is of the same age as the conglomerate.

The rocks come to the surface in three considerable areas with as many small outlying bodies. The larger areas are severally 1, 2, and 5 miles approximately in length and possess a mean width of one-half mile.

Acid Volcanics

MACROSCOPIC CHARACTERS AND OCCURENCES

The acid volcanics are more extended in areal exposure than the basic volcanics. They are both tuffaceous and massive. The fragmental material is readily recognized by mottled weathered surfaces, which owe their character to variously colored fragments contained in a light green or pink base. A fluxion arrangement of the fragments is sometimes marked.

The massive effusives exhibit a considerable range of colors and textures. Light green, gray, various shades of pink and purple, and a brilliant brick red are the notable colors. They frequently possess a compact cryptocrystalline felsitic texture, and are banded with light and dark red tints which reveal conspicuously curving and crumpled lines of flow movement. This fluxion banding is accompanied by an easy cleavage of the rock into slabs parallel to the fluxion planes, precisely as has been noted in the case of similar acid volcanics from the Lipari islands. This type is also very brittle, breaking with sharp edges which cut like glass.

The rock is usually non-porphyritic in the hand specimen, though in some instances it shows small and inconspicuous phenocrysts. It is somewhat rarely amygdaloidal, when the amygdules are of red jasper, and are characterized in a marked degree by the lenticular shape and parallel arrangement peculiar to acid lavas. In some localities, notably High rock, Hyde Park, the lava is locally an aggregation of spherulites. These spherulites vary in size from that of a pea to a butternut. They are pink or red or light greenish yellow and often exhibit concentric color tints. They may crowd the rock to the exclusion of a matrix or they are imbedded in a light green ground-mass.

The massive volcanics are exposed at the crossing of Blue Hill avenue and the New England railroad and at Cooks court, near Norfolk street, Mattapan, where flow structure and cleavage are marked. On Blue Hill avenue, in Milton, the occurrence is of the same character; on Stony Brook reservation it occurs with a granitic facies. In Grew's wood, Hyde Park, there is a ledge of very inconspicuously porphyritic volcanics. At the intersection of Arlington and River streets, Hyde Park, occurs the red amygdaloidal volcanic. High rock, Hyde Park, is a mass of spherulitic lava. At Central avenue and on Columbine road, Milton, there is exposed a deep purple volcanic, characterized by marked flow structure.

PETROGRAPHIC CHARACTERS AND MINERAL CONSTITUENTS

The primary constituents which have been preserved in the acid volcanics are the alkali feldspars, quartz, and magnetite.

Presumably either hornblende, biotite, or augite was originally present as a constituent of the groundmass, but no lime-magnesian or ferromagnesian constituents remain.

Feldspar occurs both as small scattered phenocrysts and as a component of the groundmass. Here it is sometimes granular, sometimes lath-shaped, and sometimes in radiating fibers. The lath-shaped feldspars do not show polysynthetic twinning and usually possess a parallel extinction. Microperthitic structure is a marked feature of the phenocrysts. Polysynthetic twinning is not uncommon. Extinctions indicate that albite, orthoclase, and anorthoclase are the species represented.

Quartz rarely occurs as a phenocryst, but is a constituent of the groundmass. That the magnetite is often titaniferous is indicated by an alteration to leucoxene. It also alters freely to hematite.

The secondary constituents are pinite, epidote, kaolin, quartz, sericite, hematite, and leucoxene.

In all the red material hematite is disseminated as a microscopic dust, giving color and preserving structures. Piedmontite occurs rarely in small quantities in the feldspars and along cracks.

The purple volcanics contain both magnetite and hematite as pigment, while in the case of the light green volcanic the color is due partly to the presence of epidote, but chiefly to pinite, a secondary product derived from the alteration of the feldspathic groundmass and from the phenocrysts.*

The gray volcanic is very feldspathic and comparatively free from iron oxides and other pigments.

The structures found in these lavas are the granular, trachytic, porphyritic, perlitic, fluxion, amygdaloidal, and spherulitic.

A homogeneous quartz-feldspar mosaic constitutes the granular groundmass, and, combined with flow structure, characterizes much of the lava. Associated with this presumably secondary crystallization are microscopic colorless spherulites, usually occurring in bands. The fibers are negative and feldspathic. When feldspar predominates in the groundmass the structure passes into the trachytic. The feldspar is lath-shaped and shows parallel extinctions or inclined extinctions with a small angle.

These feldspathic volcanics recall the Westfalen quartz-keratophyres and the bostonite of Marblehead neck.

Where the lava was originally vesicular the vesicles are now filled with cryptocrystalline silica. In one case a lithophysal vesicle shows crystals attached to the concentric walls and now replaced by silica.

The perlitic structure is associated with the spherulitic. The latter is found most abundantly in the mass constituting High rock, in Hyde Park. The slides are crowded with spherulites which possess a polygonal outline as the result of mutual interference.

In some cases the radiating structure is well preserved and the fibers are both positive and negative. The micropoikilitic structure may be combined with the spherulitic or may replace it altogether, or may be confined to the groundmass. Small phenocrysts of perthitic orthoclase often occur in the center of the spherulites and are distributed irregularly through the section.

In other cases the original radiating and branching spherulitic structure is indicated in ordinary light only by the iron oxide (hematite), while in polarized light an extremely fine granular quartz crystallization replaces the original structure. In the groundmass associated with these altered spherulites are found flow structure, perlitic parting, and a secondary micro-poikilitic structure occur. Orthoclase and an acid plagioclase feldspar are the phenocrysts; calcite and epidote are the alteration products.

FRAGMENTAL ACID VOLCANICS

The fragmental volcanics are exposed near the crossing of Blue Hill avenue and the New England railroad. They are especially well displayed in ledges north of the railroad, on Blue Hill avenue south of Brook street, Milton; near Harvard street and Mount Hope cemetery; in a quarry near Mount Calvary cemetery, on Rutledge road, Rugby, at the intersection of River street and the Providence railroad, and south of Norfolk street and the New England railroad. This tuffaceous material varies from a fine grained consolidated ash to a breccia composed of fragments one to two inches in diameter. In two cases the "aschen structur" which has been described by Mügge* is a feature of the tuffaceous volcanic.

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* W. O. Crosby: Relations of the pinite of the Boston basin to the felsite and conglomerate. Tech. Quarterly, February, 1889, pp. 248-252.

The forms which make up that structure only appear in ordinary light, and are entirely obscured with crossed nicols by the extremely fine quartz-feldspar mosaic which replaces the original fragmental and glassy character of the lava. South of Norfolk street and the New England railroad a light green volcanic, breaking readily into slabs, shows this structure. There is a uniform alteration of the replacing groundmass to pinite, which gives the light pea-green color to the rock. The other occurrence of this structure is in the case of a large boulder of a blood-red color which was found in the woods near Blue Hill avenue, Milton. The structure is emphasized in ordinary light by the pigment hematite, and obscured in polarized light by homogeneous crystallization. The original fragmental character is, however, indubitable.

In other instances where the fragmental character of the rock is obscured in the hand specimen its obliteration is aided by the uniform alteration of the secondary quartz-feldspar crystallization to pinite.

With these exceptions, the tuffaceous and brecciated character is always apparent in the hand specimen. The angular fragments exhibit a variety of shades—pink, red, purple, green, and other tints. The fragments are quartz, feldspar (orthoclase, albite), aporhyolite, and spherulites. The fragments of aporhyolite often exhibit remarkably well preserved perlitic parting or fluxion structure or "aschen structur." In the tuff on Blue Hill avenue south of Brook street the fragments are mainly aporhyolitic, and have all been recrystallized and largely altered to pinite and epidote. Orthoclase remains as an original constituent.

The fragmental character is often obscured, and sometimes completely lost in polarized light, by recrystallization. This is true of all the tuffaceous material from the neighborhood of Mount Hope and of Mount Calvary cemetery. In the latter locality the true character of the rock is only obscured, but not destroyed in polarized light, because the crystallization of the fragments and the matrix is not uniform. Some fragments have a secondary spherulitic crystallization, in which case the spherulitic fibers are negative. The fragments are very heterogeneous in size and character, and the rock may be termed an agglomerate. These agglomerates are of a green color, the result of the production of pinite, and contain in some cases fragments crowded with white kaolinized spherulites from the size of a pinhead to a pea.

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*O. Mügge: "Untersuchungen über die Lenniporphyre in Westfalen und der angrenzenden Gebieten." Neues Jahrbuch f. Min. Geol. u. Pal., B. B. viii, 1893.

Between Mother brook and the Providence railroad there is exposed a tuffaceous volcanic. From the same locality comes a specimen of crushed and recemented granite. The slide shows broken granitic quartz and feldspar cemented by a fine grained silicious crystallization. Pinite is abundantly developed in this cement and gives its color to the rock. This specimen shows no volcanic fragments. The aporhyolitic tuff, which was not sectioned, is a purple and gray rock, free from pinite, with plain evidence of its clastic character on the weathered surface.

At the corner of River street and Glenwood avenue there occurs a fragmental rock that might be classed with igneous conglomerates. The rock is of a medium green color, and is of a compact character on the fresh surface, but exhibits its clastic character on weathered surfaces. The fragments are subangular and rounded. The slide shows them all to be of an igneous origin—quartz, orthoclase, and plagioclase, aporhylite, and aporhyolitic ash. Pinite is more or less developed.

The localities where pinite is the predominating alteration product are the following: Near the crossing of Blue Hill avenue and the New England railroad; on Blue Hill avenue south of Brook street, Milton, and on Central avenue, Milton; at the quarry near Mount Calvary cemetery; at the intersection of Glenwood avenue and River street, Hyde Park; Stony Brook reservation, Hyde Park; between Mother brook and Providence railroad, and, finally, south of the New England railroad, on Norfolk street, in Mattapan.

In the latter locality it is very characteristically developed. The development of pinite is much more marked in the tuffaceous than in the massive volcanics, though not absolutely confined to the former.

Stony Brook reservation embraces some two square miles of the acid volcanics. The material collected from this area exhibits gradations into a highly silicious granite. Passing from south to north, the formation is first a green non-porphyritic aphanitic rock, which possesses a very fine grained groundmass, with phenocrysts of quartz and albite. The alteration is mainly to pinite and epidote. Farther to the north the rock becomes less fine grained and fresher, the phenocrysts larger and more numerous. The feldspars are perthitic, and the quartz granulated or with undulatory extinction. The micropoikilitic structure shows itself in the groundmass. The rock approaches a granite in appearance. It is a fresh medium grained light gray rock.

Still farther to the north there is exposed in the road-cut a true granite showing no ferro-magnesian constituent.

CHEMICAL COMPOSITION

The following is an analysis* of the acid volcanics of the Neponset Valley basin:

SiO_2	72.85
Al_2O_3	12.92
Fe_2O_3	2.98
CaO	0.90
MgO	0.38
Na_2O	7.08
K_2O	3.01
Trace of MnO and P_2O_5 Co_2	None
Loss by ignition (H_2OCo_2)	0.65
Total	100.77

The chemical analysis shows these volcanics to be related to the rhyolites, differing from the normal rhyolite, however, in possessing a high soda percentage. They are closely related to the soda-rhyolite or quartz-keratophyre.

The predominant feldspar is a soda feldspar. The original constituents may be estimated as follows:

Quartz	18.02
Orthoclase	17.85
Albite	60.01
Ferro-magnesian constituents and lime feldspar molecule	3.49
Other constituents	.63
Total	100.00

The chemical relationship to the quartz-keratophyre is borne out by a general resemblance in the thin-section. The trachytic alkali feldspars, the perthitic and plagioclase phenocrysts, the absence of apatite and of ferro-magnesian constituents ally them with the quartz-keratophyres.

It has been suggested to the writer that the prefix "apo" should be restricted to that kind of metamorphism in which textures and structures are preserved, and not confined in its application, as heretofore, to rocks which were originally glassy. With this the writer fully concurs.

This usage does not conflict with the present use of "meta," which remains the general prefix for metamorphic rocks, representing all kinds of alterations in any rock.

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*Analysis made by Dr W. H. Walker in the laboratory of the Massachusetts Institute of Technology from composite samples carefully collected for the purpose.

It covers the original definition of the prefix. and embraces all those rocks which under that definition have received the prefix "apo." It will include, in addition, those altered effusives which may or may not have been perfectly glassy, but which, with altered constituents, still show the structures of lavas. Under this usage the prefix may be applied with increased confidence. With this terminology the acid volcanics of the Neponset valley become apo-soda-rhyolites.

BASIC VOLCANICS

OCCURRENCE AND PETROGRAPHIC CHARACTERS

At the crossing of Blue Hill avenue and the New England railroad both volcanics are exposed in the railroad cut. The basic rock occurs as a dike in the acid eruptive. It is a compact, fine grained, dark green chloritic rock, confusedly traversed by joint-planes. The weathered surface and the joint-planes are iron-stained, and the latter are so numerous as to render it difficult to obtain a fresh fracture.

The specimens from this locality show a nearly complete alteration of mineral constituents and a preservation of structure. The alteration products are calcite, chlorite, quartz, epidote, and kaolin.

Epidote occurs as a cloudy yellow aggregate, filling the interstices of the lath-shaped feldspar, the outlines of which still remain. The feldspar substance is so completely replaced by calcite, chlorite, kaolin scales, and quartz as to render it impossible to determine the species. Magnetite is sparingly distributed and there are some remnants of iron pyrites undergoing alteration to limonite. The structure is trachytic and inconspicuously porphyritic. Flow movement is indicated by the arrangement of the lath-shaped feldspar microliths.

West of Oakland street and south of the New England railroad, not far from the preceding locality, the basic volcanic occurs as an aphanitic dark purplish rock, much jointed, with a development of chlorite on the joint faces.

This rock is characterized by comparative freedom from the alteration products—chlorite, calcite, and kaolin. The feldspar is correspondingly fresher, and extinction measurements indicate albite as the species. There is scanty calcite and much epidote and magnetite present. These minerals, with the plagioclase, constitute the rock. The structure is micro-ophitic combined with flow movement.

At the same locality a dike of the basic igneous rock occurs. The rock is lighter colored than the above and differs in showing much greater alteration of the feldspar. The feldspar is too thoroughly altered for determination of species. The alteration product is for the most part kaolin. Cloudy and granular epidote fills the interstices. Chlorite and magnetite are also present. The structure is trachytic where not obscured by secondary products.

On Norfolk street, near Cooks court, occurs a great mass of these lavas. The rock of this locality resembles closely that already described. It is very fine grained and almost structureless. The original constituents are more or less completely replaced by calcite, chlorite, epidote, and quartz. The groundmass polarizes but faintly, and may have originally been, in part, glass. The feldspathic microliths are obscured in outline and their species can not be determined.

On Morton street near Codman, in Dorchester, the basic volcanic occurs as an aphanitic dark green rock, obscurely mottled with fine red jasper areas, and with jasper deposited along the walls of cracks. The slides show the same structureless or faintly ophitic groundmass, with epidote, chlorite, quartz, leucoxene, and the iron oxides as constituents. There are altered plagioclase phenocrysts. Hematite replaces completely some phenocrysts resembling olivine in outline.

On Delhi street, in Mattapan, occurs a very similar volcanic. It is like the Morton street occurrence both in the hand specimen and in the slide.

The alteration to chlorite and epidote is so far advanced as to disguise the original constituents. One untwinned feldspar phenocryst whose substance has not completely disappeared shows an extinction of 11° The groundmass polarizes very faintly and seems to be composed of altered orthoclase. There is considerable magnetite in the section and some secondary quartz.

A basic volcanic exposed in a high ledge on the west side of Central avenue, Milton, is coarse grained and amygdaloidal. It also shows great alteration. There are considerable areas of epidote, chlorite quartz, and calcite.

The structure in some cases is trachytic and porphyritic and the feldspar still comparatively fresh. Again, the extinctions on 010 and 001 and the maximum equal extinction angle indicate albite as the species.

In this locality the rock exhibits a marked cleavage, parallel to which it breaks in slabs about one-quarter of an inch in thickness.

BASIC FRAGMENTALS

Associated with the massive volcanics at Cooks Court and on Rockville street near Blue Hill avenue are tuffs. At Cooks court the tuffaceous character shows on the weathered surface. The rock is comopsed of angular fragments of plagioclase, quartz, orthoclase, of basic, and of acid lava.

At Rockville street there occurs a dark purple tuff. It is composed of heterogeneous fragments of basic volcanic, porphyritic or non-porphyritic or amygdaloidal, a little of the aporhyolite, and some jasper. These fragments are contained in an exceedingly fine grained silicious cement· The tuff is completely altered. Chlorite, epidote, calcite, hematite, and magnetite are the secondary constituents.

CHEMICAL CONSTITUTION AND NAME

The following is an analysis* of the basic volcanic of the Neponset Valley basin:

SiO_2	53.75
Al_2O_3	18.37
Fe_2O_3	8.28
CaO	3.22
MgO	5.63
Na_2O	7.05
K_2O	1.20
Loss by ignition $\left\{ \begin{matrix} H_2O \\ Co_2 \end{matrix} \right\}$	3.34
Trace of P_2O_5 MnO and CO_2	Very slight
Total	100.84

The analysis shows a remarkably high soda content. This is so abnormal that the correctness of the analysis was called in question. A new analysis was made, but the result showed no alteration in the soda content. In the slides there is no indication of the presence of nephelite or analcite. Whether the pyroxene or amphibole, which may have been original constituents of the rock, was a soda pyroxene (ægerine) or a soda amphibole (glaucophane or riebeckite), there is no absolute means of determining, but there is no indication that this was the case. If therefore all the soda present is combined with silica to form feldspar, this feldspar will constitute 59.75 per cent of the rock, while orthoclase constitutes 7.11 per cent, and the other constituents 33.14.

That some proportion of the soda was consumed in a magnesian silicate is not improbable, because of the low silica percentage. If the soda and potash are used exclusively to form feldspar, sufficient silica remains to combine only with 2.66 per cent of the lime. Some of the lime may, however, have been brought to the rock in solution at the time of the formation of the secondary products—epidote and calcite.

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*Analysis made by Dr W. H. Walker, of the Massachusetts Institute of Technology, from composite material carefully collected for the purpose.

The analysis falls within the chemical range of the andesites, though the ruling feldspar is more acid than is characteristic of the normal andesite. While the chemical composition resembles that of the banakite dike from Hoodoo mountain,* the Neponset volcanic does not, like the banakite, contain analcite; it is essentially an altered andesite, rich in soda. In accordance with the proposed use of the prefix apo, these volcanics, which preserve the structures of the original type, while the constituents are more or less completely altered, may be termed *apoandesites.*

PORPHYRITIC VOLCANIC

In the woods on the west side of Central avenue, Milton, there is exposed a deep purple volcanic with a conspicuously porphyritic structure. The phenocrysts are white, broadly lath-shaped feldspars; the rock is very feldspathic. It possesses a groundmass composed of a mosaic of feldspar grains, with possibly a little quartz. This groundmass is crowded with feldspar crystals varying greatly in size. Twinning by the albite and carlsbad law are the rule; pericline twinning is rare. Extinctions on 010 and 001 and the maximum equal extinction angle indicate that albite is the predominating feldspar.

Parallel extinction on some of the microliths indicates that orthoclase is also present.

Lath-shaped and rudely hexagonal aggregations of magnetite replace some ferro-magnesian constituent whose substance has completely disappeared.

On the east side of the avenue a ledge of breccia furnished a pebble of a similar feldspathic rock.

It shows some alteration to chlorite and epidote, but on the whole is much fresher than the andesite, and is, like the porphyry just described, very feldspathic. The structure is panidiomorphic and porphyritic. The feldspars, which constitute almost the entire rock, are rectangular and broadly quadratic. They often show a central alteration to epidote or chlorite.

Repeated twinning is not common and parallel extinction shows that considerable orthoclase is present, though not the ruling feldspar. Maximum equal extinction varied from 12° to 16°; extinction on the untwinned sections was repeatedly 19° or 20°. From this it was inferred that albite was again the predominating feldspar.

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* J. P. Iddings: Absarokite-shoshonite-banakite series. The Journal of Geology, vol. iii, 1895, p. 947.

Aggregations of magnetite, chlorite, and epidote, as before, represent the ferro magnesian constituent and suggest biotite by their forms.

In a cut on the New England railroad near River Street station there is exposed a curiously brecciated porphyry.

Independently of its brecciated appearance, the rock resembles the purple porphyritic volcanic from Central avenue, Milton. A somewhat lighter shade of purple alone distinguishes it in the hand specimen, and in the slide there is an equally close resemblance.

There is the same fine grained granular groundmass crowded with lath-shaped and quadratic feldspars, not often showing polysynthetic twinning.

The extinctions show a soda feldspar, and more nearly correspond to the albite molecule than to any other.

Former ferro-magnesian constituents are represented by areas of chlorite, epidote, and calcite, with a heavy border of granular magnetite.

That these albite-orthoclase effusives belong near the trachytes can hardly be doubted. In the absence of a chemical analysis of this material, no more exact affiliations can be determined. If we adopt the nomenclature used in the case of the aporhyolites and apoandesites, these volcanics will be called apotrachyte porphyry.

Conclusions

The volcanics of Neponset valley thus fall into three groups—the apo-soda-rhyolite, apotrachyte porphyry, and apoandesite. They are characterized by a high soda content and by great alteration of original constituents, with the preservation of original structures.

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GEOLOGY OF THE WICHITA MOUNTAINS

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INTRODUCTION

For a region of such geologic interest the Wichita Mountain belt has been but little studied. Rising, as these mountains do, through the latter sedimentaries of the prairie region midway between the Rocky mountains and the crumpled paleozoics of western Arkansas, they afford a key to many of the geological problems of the great plains. A detailed study of the region is of the first importance, if we are ever to know the geology of the plains region. While the present study is far from being sufficiently detailed to answer many of these problems, it is believed that important information worthy of permanent record has been obtained. The survey was made within the present year, the month of May being devoted to the task.

In the course of the work the author had the constant and valuable assistance of Mr J. W. Finch, to whom he is indebted for many facts of observations and suggestions of value. He is also in debt to Professor R. D. Salisbury for private notes collected on a reconnoissance trip earlier in the present year. Permission to publish the results is generously given by General Manager H. A. Parker, of the Chicago, Rock Island and Pacific railroad, under whose direction the work was done.

Previous Work in the Region

The "Wichitas" are a detached group of mountains of general east-west trend located within the Kiowa and Comanche reservation, in southwestern Oklahoma. They are not within the area open to settlement, and perhaps in part for this reason have long been attractive to the prospector. They have never been geologically surveyed in detail, though several geologists have made reconnoissance trips through the region. The first of these was George G. Shumard, who was attached to Marcy's expedition to the sources of the Red river in 1852.* The specimens collected by this expedition were studied by Edward Hitchcock,† and chemical analyses of the ores and soils were made by C. U. Shepherd.‡ In 1889 Messrs T. B. Comstock and W. F. Cummings, of the Texas Geological Survey, made a trip through the mountains, and their results are given in the First Texas Report.§ This is the only geological paper especially devoted to the Wichitas which we have had up to the present. There have, however, been several brief papers dealing with the Wichitas in connection with neighboring areas. Among them is a paper published by T. Wayland Vaughan last July.|| The latter paper includes petrographic notes by Doctor A. C. Spencer. Robert T. Hill determined the height of mount Scott,¶ and has made several incidental references to the geology of the region.**

Cummings and Comstock devoted more time to the area than any previous investigators, but their opinions seem to have been very largely colored by what they had previously seen in central Texas. The present work has shown that they are fundamentally wrong in referring the granite to the pre-Cambrian, since it cuts and metamorphoses Ordovician strata. They are also clearly mistaken in indorsing Hitchcock's†† opin-

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*Senate Doc., 2d sess., 31st Congress, vol. 8, Washington, 1853, Appendix D.

†Op. cit.

‡Op. cit., Appendix C.

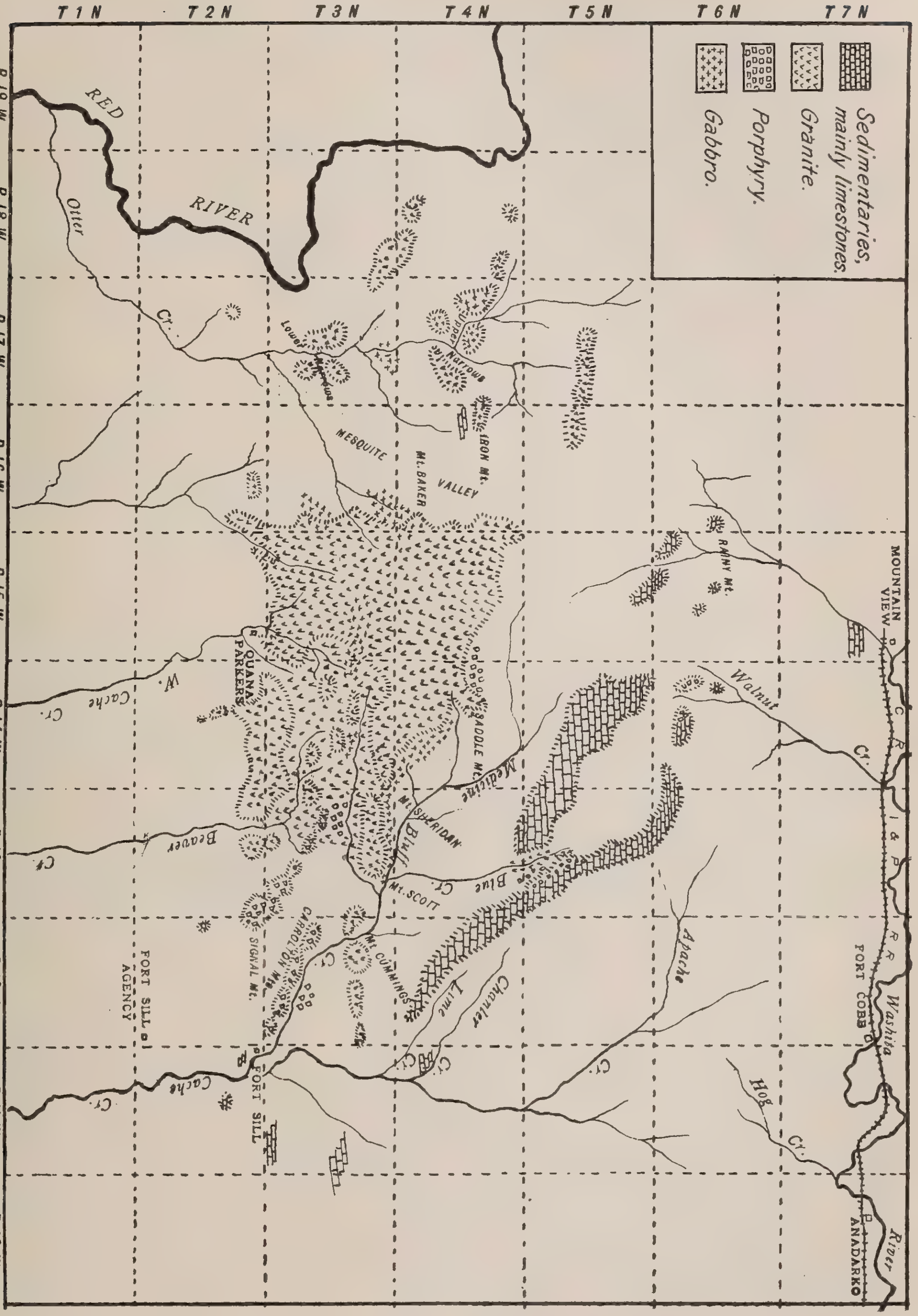
§Geol. Survey Texas, vol. i, pp. 319-328.

||Amer. Geologist, vol. xxiv, 1899, pp. 44-57.

¶Ibid., vol. vii, 1891, p. 119.

**Ibid., vol. vii, p. 254; vol. vi, pp. 252-253. Amer. Jour. Sci., (3), vol. xlii, 1891, pp. 122-123.

††Geol. Survey Texas, vol. i, p. 321.



H. Foster Bain

FIGURE 1.—*Sketch Map of Wichita Mountains*

ion that there has been recent volcanic activity in the region. The greenstone dikes are certainly the most recent igneous rocks. The tuffs and rhyolites found are pre-Cambrian, and the resemblance of certain of the mountains to "an ancient crater" is fanciful only. It has been impossible to recognize all the peaks named by this party and to perpetuate these names. Wherever the recognition seemed secure the names have been used. Mount Webster, located and ascended by Marcy's party, seems now unknown. From the general references to its position and the sketch given of its outline it seems probable that it is the peak now known as Baker, but in the absence of accurate maps there will for some time be confusion regarding the geography of the area between Saddle mountain and the Mesquite valley.

The maps of the region are quite imperfect. The land survey seems to have been more than usually inexact. The sketch map (figure 1) given with this paper is from a blue print of a map made by the railway engineers. The position of the various mountains is set down from checked compass readings, where other data are lacking.

PHYSIOGRAPHY

The Wichitas rise abruptly from the great prairie plain about midway between the Washita and Red rivers. Cache creek flows through the low, circling hills of the east end, and on the west the North fork of Red river separates the Wichitas from the Navajo mountains which lie in Greer county, Oklahoma.

The core of the mountains is a rugged mass of igneous rocks. On the north side, circling around the east as far west as the south side of Signal mountain, is a lower range of limestone hills of less rugged aspect and with rounded slopes. These hills rise 70 to 400 feet above the plain and are in part detached, such as Rainy mountain and the elevation near it, and in part massed together. These limestone hills are separated on the north from the main mountains by a wide valley, down which for much of the way Medicine Bluff creek flows. This stream, which by Marcy's party was evidently mistaken for the main branch of Cache creek, cuts through the porphyry of Carrollton mountains, forming a sharp bluff 250 to 300 feet high, from which the stream takes its name and which is regarded with a certain amount of awe by the Indians.

The mountains themselves consist of a series of detached and semi-detached mountains, and are crossed by wide passes which are nearly as level as the surrounding plain. Between the mountains flat grassy plains are found and spurs protrude through the plain at some distance from the main mountain mass. The exceedingly rugged topography of the mountains proper and the great detached blocks of granite which cover their surface give as a result the appearance of a deeply buried range with the tops just protruding through the plain. In a way this is a true conception of the case.

The northernmost series of hills consists mainly of limestone, but includes some porphyry, granite, and gabbro. In the vicinity of Rainy mountain they are made up of a series of detached and rounded limestone hills rising out of the prairie 70 to 400 feet and with a general dip north. East of this region, and extending from north of Saddle mountain to a little northeast of mount Scott, the hills are traversed by no pass and consist of a complicated, much folded and faulted mass of limestone, with porphyry, granite, and a little grabbro. This series of hills stretches north, with a triangular outline culminating about 10 miles southeast of Mountain view. The pass north from mount Scott is traversed by the Fort Sill-Cheyenne trail, which follows the narrow canyon of Blue creek, separating the range just described from another limestone range. The latter shows a complicated structure near the pass, becoming simpler to the northeast, where the limestone crops out on Lime and Chandler creeks. To the north the hills swing round, crescent-like, to meet the point of the limestone triangle already noted.

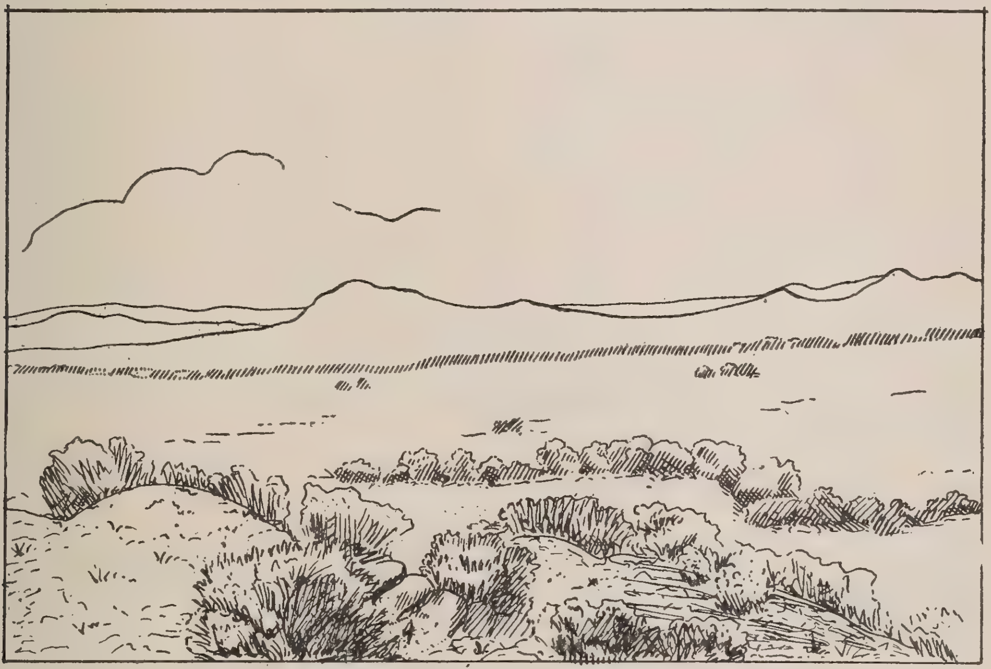


FIGURE 2.—*Sketch of Lower Narrows.*

Showing sharp granite hills with flat plains between.

South of the series of limestone hills, and separating them from the first of the granite ranges, is the broad open valley occupied in part by

Medicine Bluff creek, 5 to 7 miles wide, and trending with the mountains. The granites immediately south of this valley form the north range of the mountains proper. They extend on the east almost to Cache creek in a series of detached knobs, rising to the west and culminating in mount Cummings. The latter is separated from mount Scott, the highest peak in the mountains, 2,305 feet above sealevel and about 1,500 feet above its base, by an open pass. Mount Scott extends for about 5 miles to the west with decreasing altitude, and is separated from the next peak, mount Sheridan, by a narrower, higher pass. From mount Sheridan west to Haystack mountain, which lies a little east of south from Rainy mountain and is in the same locality as Tymatee mountain, as located by Vaughan, there are no passes proper. About midway the granite runs out to the north nearly 4 miles and culminates in the striking peak called Saddle mountain. From Haystack west nearly 10 miles is a broad mesquite plain, extending south across the entire mountains and separating the main Wichitas from a series of detached and irregularly placed mountains extending to the Red river and known locally as the Raggedy mountains.

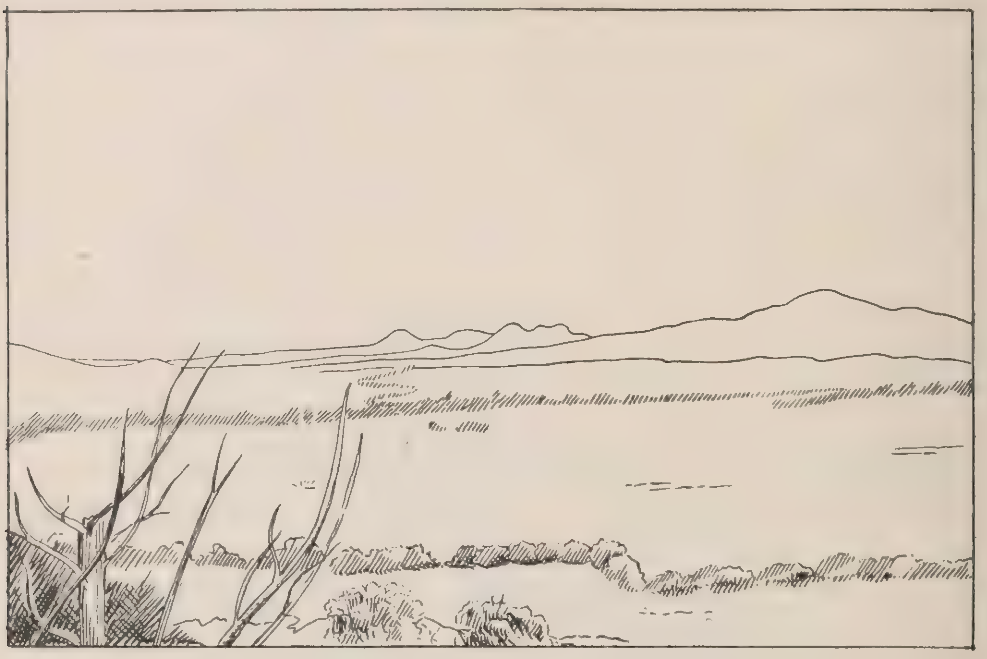


FIGURE 3.—*Sketch of Lower Narrows in Raggedy Mountains.*

Showing semi-detached character of the peaks.

South of mount Scott and the granite range of which it is the most conspicuous feature is an open valley 3 to 5 miles across, broken by irregular granite and porphyry knobs rising 150 to 400 feet above the general level of the plain and closing in to the west. Signal mountain and the range of porphyry hills, including Medicine bluff, and called the Charlton mountains by Comstock, pierce this valley from the southeast with a series of elevations of decreasing height and extending as far west as the longitude of mount Sheridan. South of the porphyry hills is the main granite mass of the south range. This begins in an outlying bunch of hills east of Beaver Creek pass and extend unbroken westward to the broad pass north of Quana Parkers, a Comanche chief living on West Cache creek. About 2 miles east of Quanas the range throws out a long low spur to the south. West from Quanas the mountains are unbroken to the Mesquite valley, already described. The intermontane valley is more and more broken by mountains to the west until it becomes too obscure for recognition, and the mountains face the Mesquite valley along the eastern edge in a practically unbroken range.

West of Mesquite valley and extending to the Red river is a group of detached peaks known locally as the Raggedy mountains. Otter creek flows through them and at two points on its course cuts gorges known as the Upper and Lower narrows. The former is located in township 4 north, range 17 west, and latter in the southern portion of the first township south of this. Iron mountain, as located by Vaughan, is one of the peaks lying northeast of the Upper narrows, and Round mountain would lie west of them, in the region where there has been so much surreptitious prospecting.

Rocks Present

The rocks forming the Wichita mountains include granites, gabbros, and porphyries in their various phases, and a series of Cambrian and Ordovician sediments, principally limestones. The oldest rocks in the region are the Raggedy Mountain gabbro and the Carrollton Mountain porphyry. The relations of the two are not certain beyond dispute, but apparently the gabbro is the older. In a general way the gabbro is more prominent in the western portion of the mountains, being especially well developed in the Raggedy mountains, while the porphyry is more common in the east. Both are pre-Cambrian and perhaps Archean. These rocks formed an old land-mass or island around which the sediments were laid down. The latter begin with a conglomerate carrying fragments of porphyry and gabbro, but none of granite, and run up through the quartzose sandstone, calcareous sandstone, and arenaceous limestones of the Blue Creek series, and so into the Rainy Mountain limestone proper. At its base the series carries definite Cambrian fossils, and higher up Ordovician (Lower Silurian) fossils are found. Allowing for dip and faults, a thickness of a trifle over 4,000 feet of these beds is exposed.

They are best displayed on the north side of the mountains, but sweep around the eastern end, and are found so far west as Signal mountain on the south side. Beyond this point they seem to be buried beneath later material.

The Quana granite, so named from a prominent chief, near whose lodge it is well exposed, is eruptive, cutting the porphyry and the gabbro at many points and exhibiting all the usual contact phenomena. A great dike of granite running from mount Scott north has disturbed and metamorphosed both the porphyry and the limestone, proving that the granite is later in age than either. Additional proof is found in certain beds, called here the Geronimo series, east of Cache creek, near Fort Sill. In some mesas nearly east of Fort Sill agency, there is a series of sandy shales capped by limestone. These are east of the Fort Sill limestone quarries and from the dip presumably represent a higher horizon. The shales include a conglomerate bed which shows fragments of the preexisting limestone, porphyry, and granite. They belong accordingly to a series later than the Ordovician, already described. The age of the series is not certain, but its appearance suggests Paleozoic.

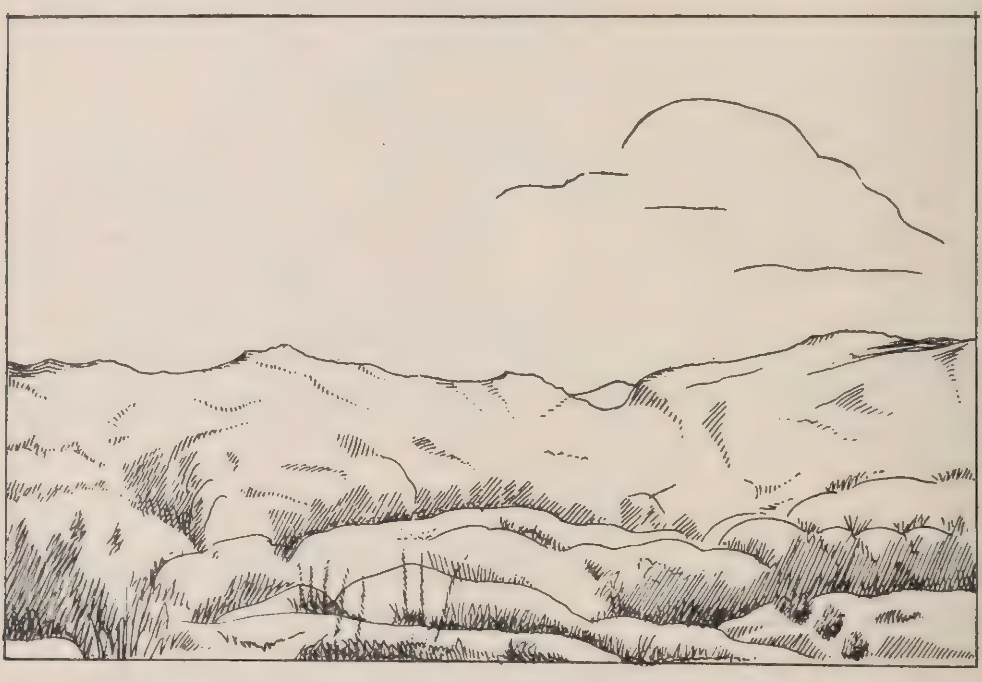


FIGURE 4.—*General View of Granite Hills of the South Range near Quanas.*
Looking south.

There is a series of dikes of fine-grained greenstone of as yet undetermined character, which cuts granite, gabbro, and porphyry alike.

There are also quartz veins in the granite and porphyry and in the gabbro in connection with granite dikes.

Recapitulating, the various rocks found in the mountains are shown in the following table:

Formation.	Character of the rocks.	Age.
Red beds.	Sandstone and shales...	Permian.
Geronimo series.....	Sandstone conglomerate, shales, and limestones; carries asphaltum.	? ?
Dike rocks..........	Fine-grained greenstones of various types.	May be later.
Quartz veins........	Cut by dikes..	May be in part earlier.
Quana granite.......	Eruptive through earlier formations and furnishing debris to the Geronimo series.	
Rainy Mountain limestone.	Blue and gray limestone folded and metamorphosed by the granite; conformable on the earlier sediments.	Ordovician.
Blue Creek series...	Conglomerates, quartzites, sandstones, running up without break into the Rainy Mountain limestone and unconformable on the earlier rocks.	Cambrian.
Carrollton Mountain porphyry.	Including rhyolites, amygdaloids, and some tuffs. The Saddle Mountain porphyry, of slightly different type, probably belongs here.	Archean (?)
Raggedy Mountain gabbo.	Including a considerable variety of basic rocks here regarded as facies of one magma. Possibly eruptive through the porphyry, but not certainly so.	Archean (?)

CRYSTALLINE ROCKS

CLASSIFICATION

As has already been stated, the central core of the mountains consists of crystalline rocks. These include three well marked and usually easily distinguished types: (*a*) granite, (*b*) porphyry, (*c*) gabbro. There are also quartz veins and greenstone dikes. There has as yet been no opportunity to make microscopic studies of these rocks, but there is no reason to believe them greatly different from the rocks examined by Spencer* and collected in the same region. What is said here is based on macroscopic observation only.

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*Amer. Geologist, July, 1899, pp. 47, 48.

RAGGEDY MOUNTAIN GABBRO

With the gabbro are classed here a considerable variety of dark basic rocks, some of which, occurring in dikes, may prove to belong rather with the diabases. The normal type is a dark holocrystalline rock showing pyroxene and labradorite. West of Otter creek the rock shows frequently great masses 6 to 8 inches across of pyroxene. Ilmenite is not uncommon, and has been mistaken for tin ore. The gabbro areas are characterized by low, almost flat surfaces (see plate 15, figure 1). The rock apparently weathers down rapidly, and east of Mesquite valley nowhere rises in sharp hills. It occurs along Medicine Bluff creek on the north flank of mount Scott, where it is coarse grained and apparently properly an anorthosite, and in the embayment between mount Sheridan and Saddle mountain. It is found in limited areas north of Medicine Bluff creek, rising from beneath the limestone. It was noted also in what has been called the central valley of the mountains, and is abundant along the west flank of the mountains facing Mesquite valley. Low knobs of this rock project through the floor of the valley, and near the Upper Narrows it forms hills rising 500 feet along the creek. The relations of the granite to the main gabbro mass is beyond dispute. Northwest of mount Scott the granite was seen to cut the gabbro at two points. Along the west flank of the mountains granite dikes running out into the gabbro are quite common. On Otter creek, about half way between the Upper and Lower narrows a boss of granite rises through a sheet of gabbro and sends out stringers into the latter on all sides. Figure 2 of plate 15 represents a horizontal granite dike cutting the gabbro of one of the high hills west of Otter creek. The presence of a small stringer of granite running off from the dike and a sharp covered block of gabbro imbedded in the granite is conclusive.

The relations of the gabbro to the porphyry and associated rocks is not so clear. In the Blue Creek canyon a gabbro area was noted wholly within the porphyry and apparently under it. Near the same area a dike of gabbro cuts the porphyry. The gabbro, as well as the porphyry, has furnished material to the Cambrian basal conglomerates. Not all, however, of these basic rocks belong with the main gabbro mass, since in the Carrollton mountains a quartz vein cutting the porphyry is in turn cut by a greenstone dike.

CARROLLTON MOUNTAIN PORPHYRY

There are two types or porphyry found in the region. The first has a fine pink ground-mass, is set with phenocrysts of orthoclase and clear

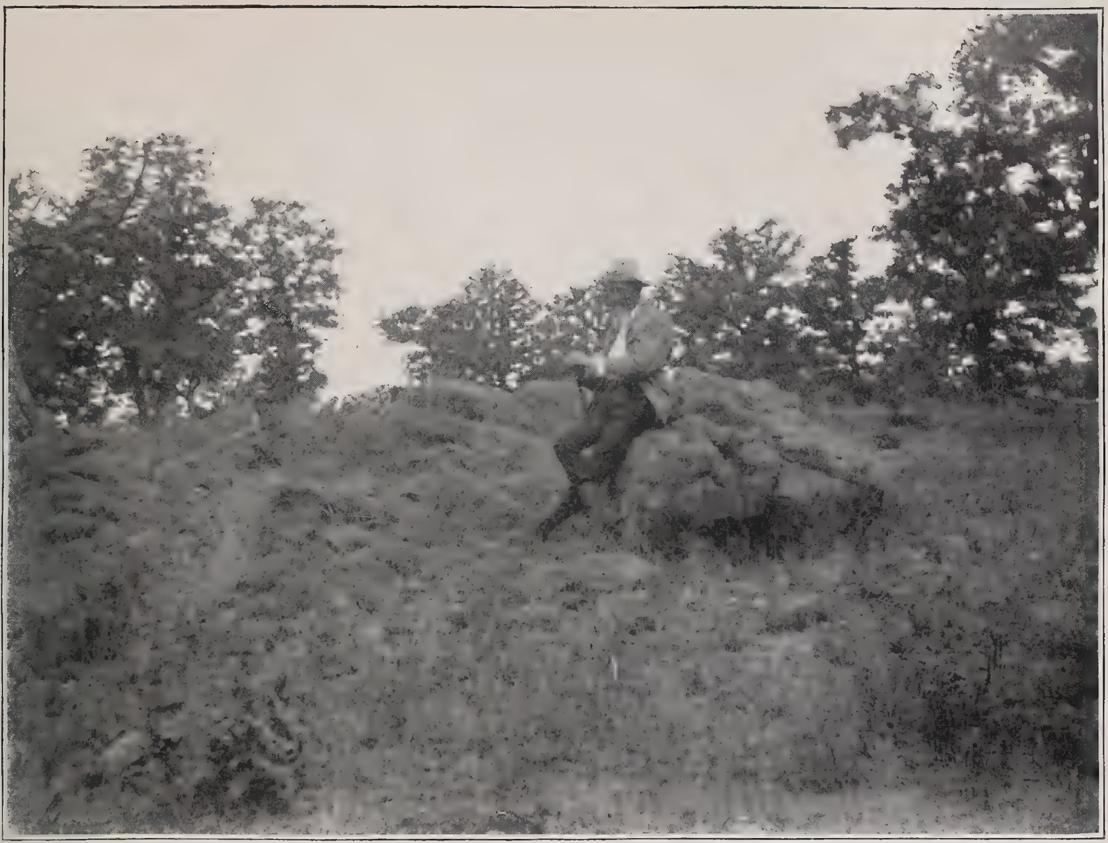

Figure 1.—Typical Gabbro Surface

Showing low, rounded boulders

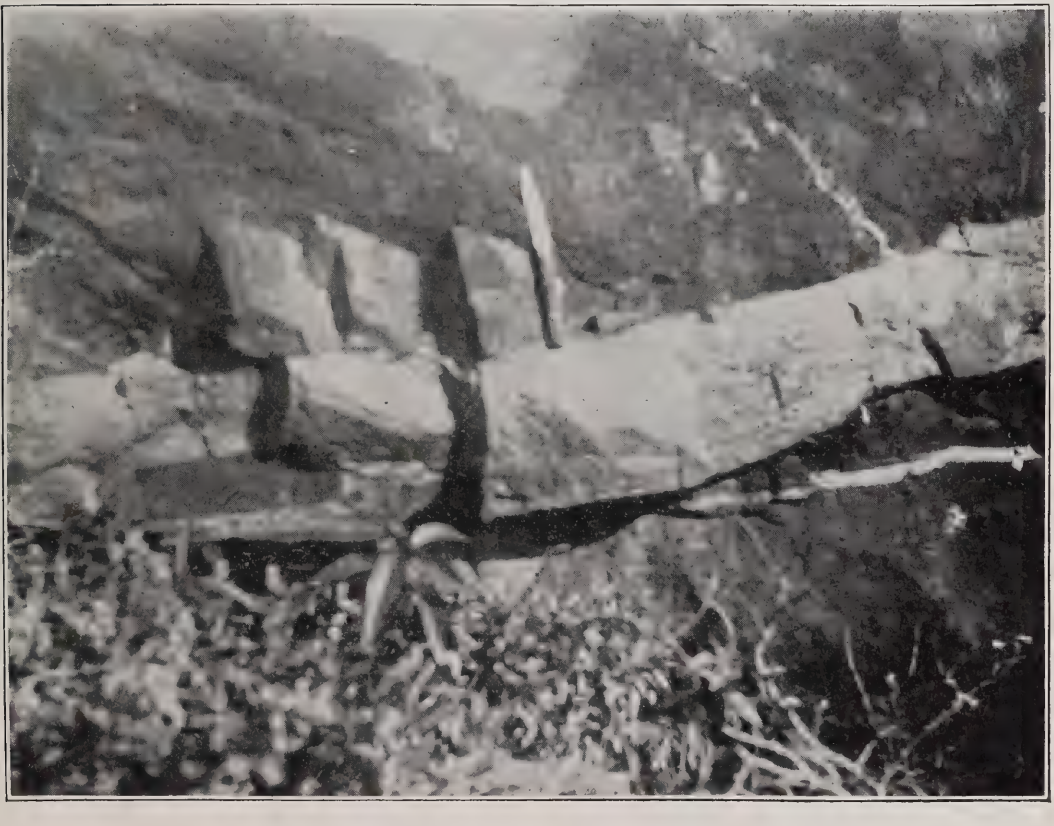

Figure 2.—Granite Dike in Gabbro

Showing stringer and horse

GABBRO SURFACE AND GRANITE DIKE

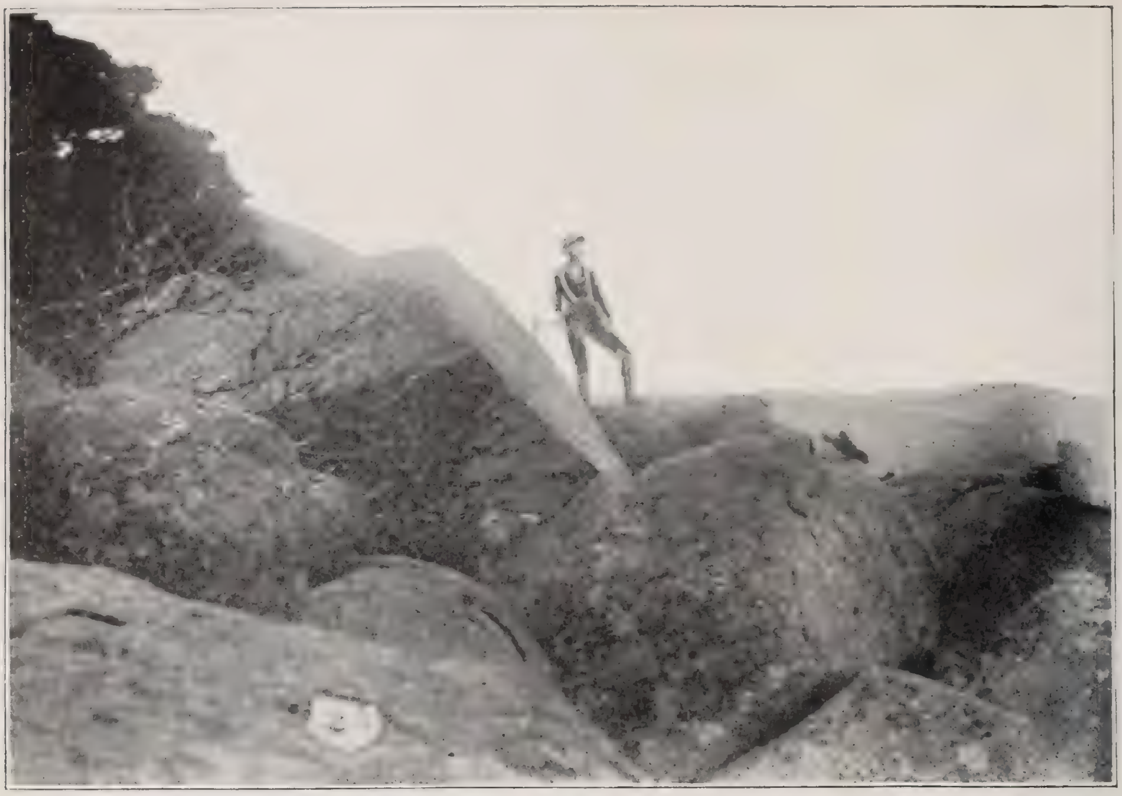

Figure 1.—Characteristic View of Granite Talus on Side of Mount Scott

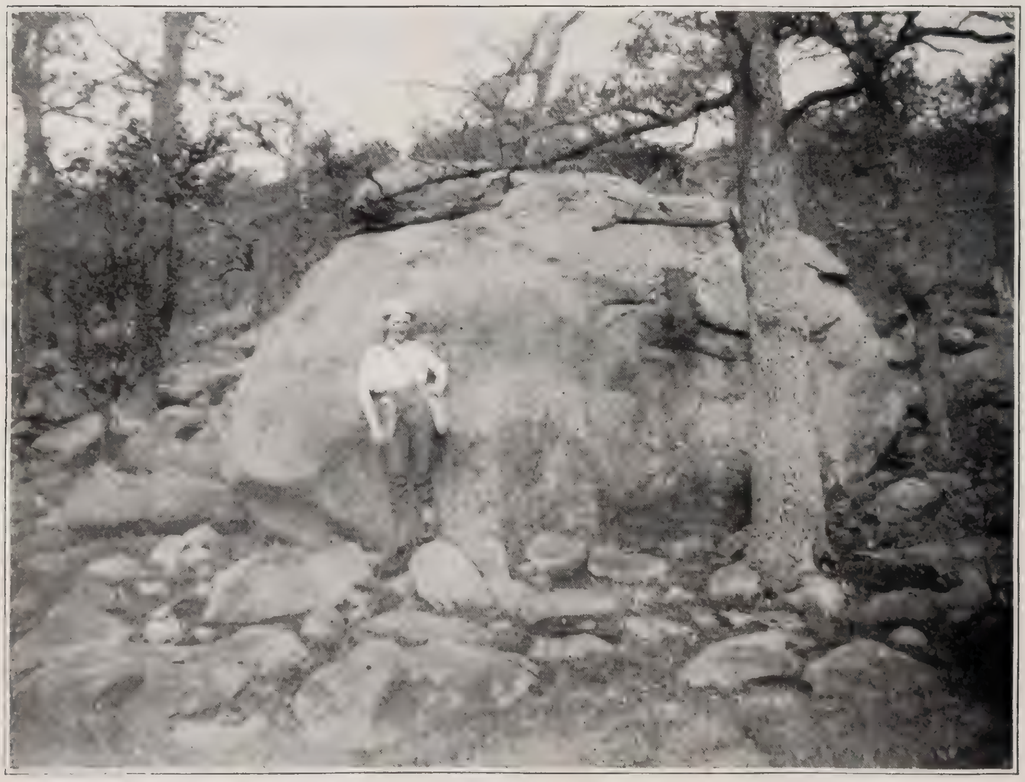

Figure 2.—Granite Boulder on Tableland South of Mount Scott

Illustrating tendency to form large surface boulders

GRANITE TALUS AND GRANITE BOULDER

quartz. The latter is especially common in the porphyry of the Carrollton mountains. In general, the porphyry does not take on a granitic phase, though a few such instances were noted. In Blue Creek canyon there are associated with the porphyry certain eoryolites, showing lithophysæ and other rocks apparently rhyolitic and tuffaceous. It is this pink porphyry which forms the common type of the mountains and is seen south and east of mount Scott, in the Carrollton mountains, in Signal mountain, and in the limestone hills north of the main range, where it forms the platform upon which the Cambrian conglomerate rests and has been brought up by faulting. The second type of porphyry was noted only along the north flank of the main granite range west of Saddle mountain. It differs from the usual type in having a much darker ground-mass, which may be a wholly inconsequential difference.

Wherever the porphyry outcrops it shows a characteristic topography, forming rounded hills with smooth flowing contours. It is often much shattered, and the surface of such hills usually shows many small sharp-edged fragments of rock, as distinguished from the granite and gabbro outcrops, which are characterized by rounded boulders of disintegration.

QUANA GRANITE

This is by far the most common crystalline rock in the region, and shows but little variation in character. The rock is predominantly feldspathic, with a subordinate amount of quartz and a still smaller amount of a green mineral, presumably hornblende. So far as was observed, the granite is wholly free from mica, and in fact mica was only found in two localities, where it occurs in small yellow flakes in connection with certain dikes of granular white quartz radiating from the granite mass and cutting the gabbro. Granite forms the bulk of mounts Scott, Sheridan, Baker, Haystack, and Saddle mountain, and in fact all the more prominent peaks. It weathers characteristically into large boulders marked off by joint cracks. On the top of a large tabular mountain just east of the Mesquite valley one such boulder of disintegration was seen, measuring 60 by 40 by 30 feet. Figure 1 of plate 16 shows a characteristic view on the side of mount Scott, and figure 2 of the same plate gives one a correct impression of the size of the blocks on the lowland. These boulders are so common that over much of the granite area it is difficult to find exposures of the solid rock.

The granite has suffered much deformation. Shear zones are not uncommon, and faulting with well developed slickensides was repeatedly observed. The rock is eruptive through the gabbro, as already shown, and its relations to the porphyry are quite as clear. At contacts observed on the southwest flank of mount Scott the granite was seen to send off stringers into the porphyry. It becomes, too, notably finer in grain, while the porphyry is not changed in general character, though it is badly shattered near granite outcrops. In Blue Creek canyon the porphyry platform upon which the Cambrian conglomerate was deposited has been sharply tilted by the granitic intrusion. The relations of the granite to the limestone are clear from the three facts: (*a*) At an actual contact observed on the west side of the Blue Creek canyon the dark earthy limestone had been recrystallized into a white, coarse marble; (*b*) in the same vicinity the intrusion of the granite had tilted the porphyry and its covering of sedimentaries; (*c*) the basal conglomerate contains everywhere fragments of both porphyry and gabbro, but no granite, though the latter could not have been more difficult of access, assuming it to have been pre-Cambrian.

It is only in the later conglomerates of the Geronimo series that granite pebbles appear.

LATER ERUPTIVES

At several points the granite is cut by greenstone dikes. At one point in the Raggedy mountains three generations of the greenstone, including the original gabbro, can be counted. Quartz veins, some of them granular and carrying mica, also cut the granite. The best known of these veins is the one separating the easternmost from the middle porphyry hill at Medicine bluff, in the Carrollton mountains. This vein is 12 feet wide and shows plainly on both sides of Medicine Bluff creek. It is cut by a small greenstone dike and was noted by Marcy.

SEDIMENTARIES

BLUE CREEK SERIES AND RAINY MOUNTAIN LIMESTONE

The character and relations of the sedimentary series can perhaps be best made out from the exposures around Canyon Creek camp, which was located on the Fort Sill-Cheyenne trail about 7 miles north of mount Scott and in the canyon cut by Blue creek. The trail enters the limestone hills from the south and runs for some distance on granite, believed to be a great dike running off from the Mount Scott mass. To the west is a great complex of highly contorted limestone, changing into marble at the contact with the granite, and extending with many conflicting dips nearly to Rainy mountain. Figures 1

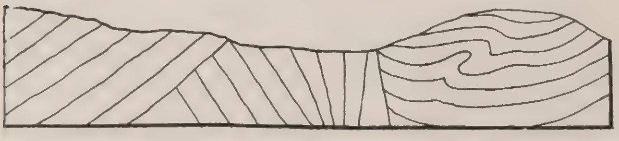

FIGURE 5.—*Crushed Anticline and Overthrust Fault in Limestone, north of Mount Scott.*

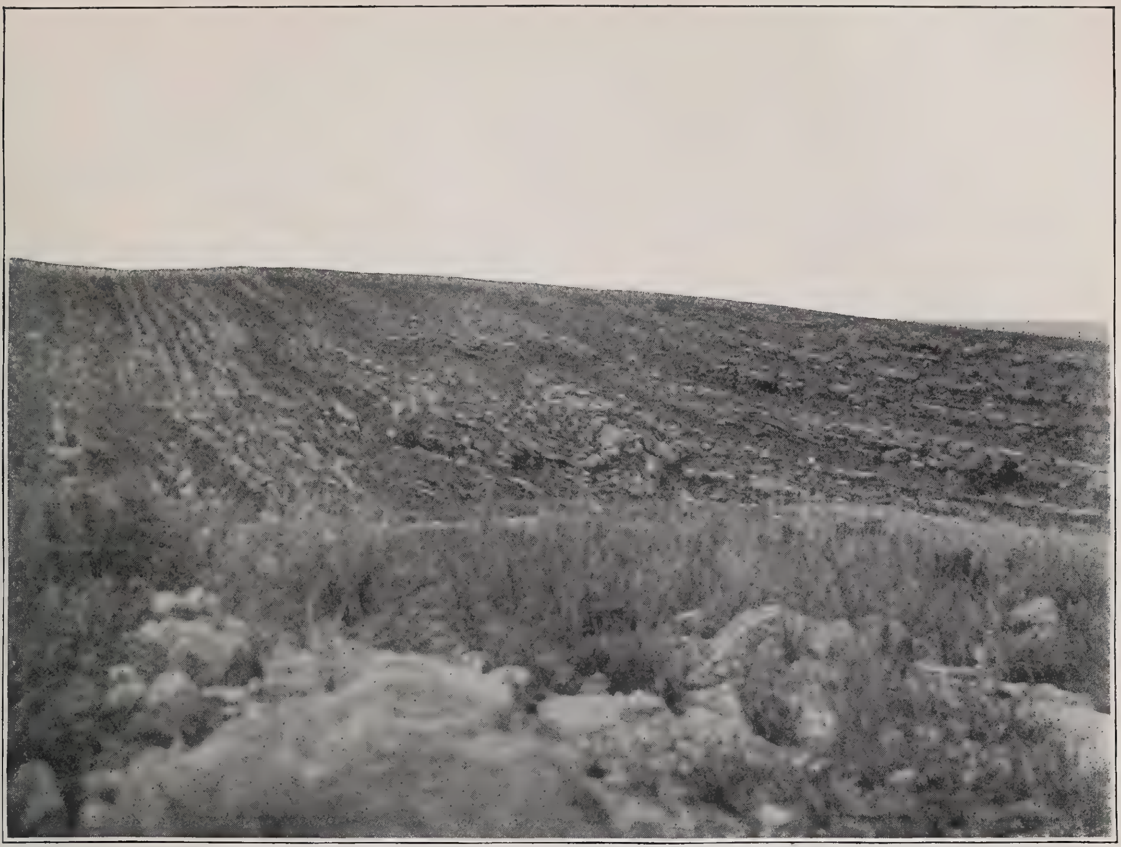

Figure 1.—Contorted Limestone West of Fort Sill—Cheyenne Trail North of Mount Scott

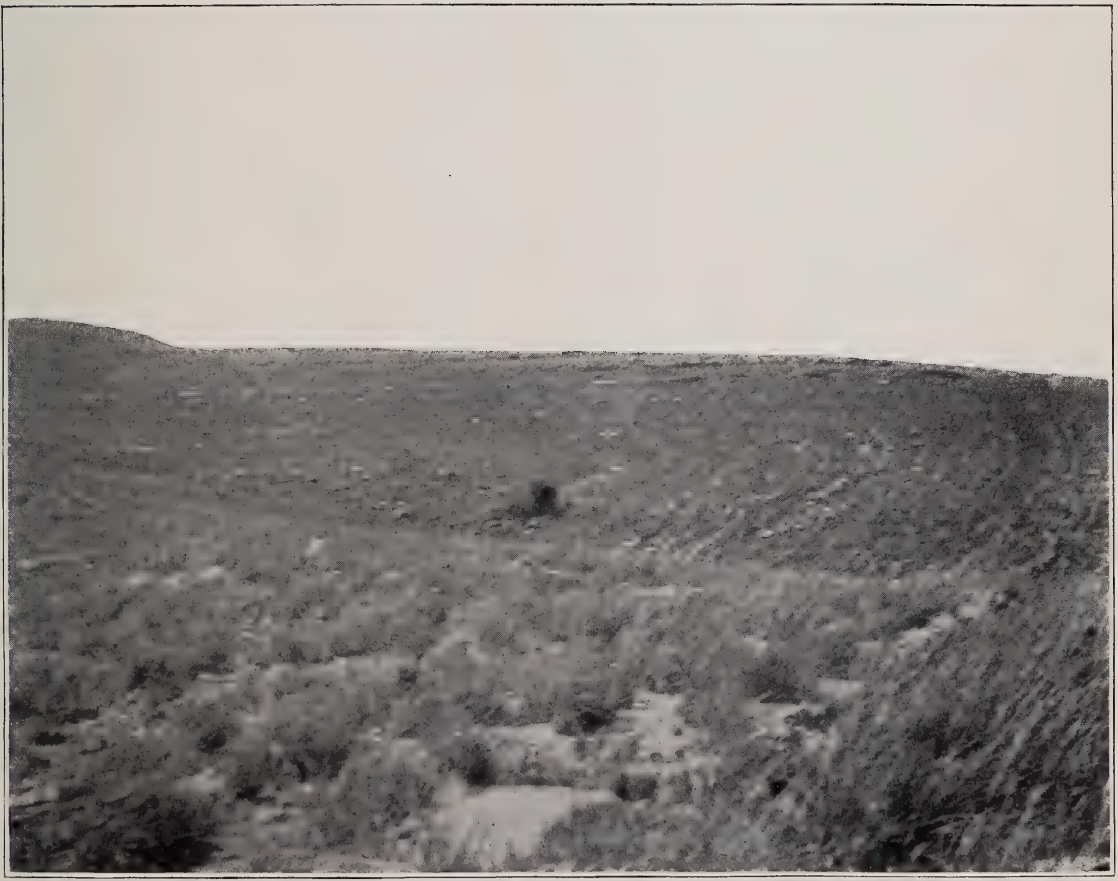

Figure 2.—Truncated plunging Anticline in Ordovician Strata North of Mount Scott

CONTORTED LIMESTONE AND TRUNCATED ANTICLINE

and 2 of plate 17 will show how sharply the limestone is folded, and figure 5 is a rough sketch of a crushed anticline and overthrust fault chosen as one of many possible illustrations. There are anticlines with almost vertical pitch, and the rocks have evidently suffered very much disturbance. It may be tentatively suggested, though the data collected hardly warrant any generalization, that the rocks seem to have been first thrown into a series of east-west folds parallel to the main mountain range, and then thrown into cross-folds by the intrusion of the local granite mass.

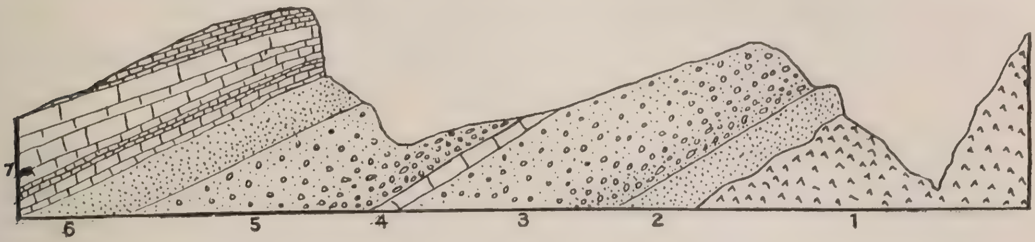

FIGURE 6.—*Sedimentaries: Blue Creek Series resting on Porphyry, north of Mount Scott.*

To the east of the trail are high porphyry hills covered by a sedimentary sequence having a fairly uniform strike and dip. Near the mouth of the canyon a fault repeats the sequence as if to enable the geologist to check his work. Figure 6 represents the basal portion of the section as far as the fault. In figure 7 the fault and repetition are shown. The general section of the beds from the base up is as follows:

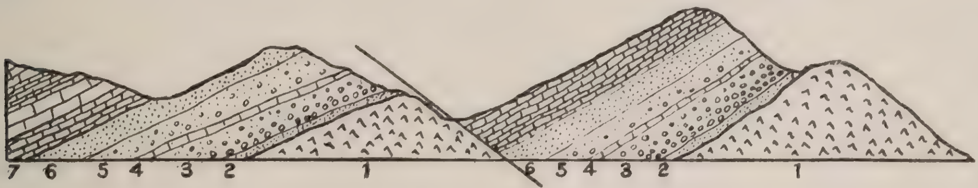

FIGURE 7.—*Repetition of Cambrian Strata by Faulting, north of Mount Scott.*

	Feet
1. Porphyry, red, usual type.	
2. Sandstone, white, rounded grains, quartzitic, with one small dip fault; dip, 28 degrees	50
3. Conglomerate, dark colored, porphyry pebbles set in matrix of green sand seemingly derived from disintegration of basic rocks; Cambrian fossils; dip, 30 degrees	250
4. Coarse grained crystalline limestone with particles of magnetite and hornblende; dip, 29 degrees	30
5. Dark sandstone, conglomeratic, with porphyry pebbles and much hornblende; dip, 24 degrees	180
6. White calcareous sandstone weathering cavernous	70
7. Limestone, blue, with fossils (Cambrian) ranging from 40 to 50 feet near the middle; dip, 29 degrees at base, becoming 5 degrees at top	110

Fault repeating first seven numbers.

	Feet
8. Limestone, thin shaly, with some sandy material	50
9. Limestone, blue, heavily bedded	450
10. Limestone, thin bedded, sandy	80
11. Limestone, heavy, blue; dip, 35 degrees	510
12. Limestone, brecciated, rounded, and angular; fragments imbedded in calcarous matrix; no evidence of especial crushing	10
13. Limestone, blue, earthy, with chert for a thickness of 100 feet 600 feet above base, and fossils near top	1,250

It is possible that numbers 10 and 11 are repetitions of 8 and 9, due to an obscure dip fault, but it was impossible to determine this absolutely. Number 13 seems to represent the same horizon as that from which numerous fossils were collected in the hills east of Rainy mountain, and would accordingly be Calciferous. According to this determination the section was not at this point carried up to the Trenton. A total thickness of more than 4,000 feet was measured in this vicinity, and it is doubted whether the combined Cambrian and Ordovician much exceed this thickness, though in view of the changes in dip and liability to faults the question must for the present remain open.

At Rainy mountain the lower beds are not shown, and the Trenton only is exposed. The Calciferous is exposed in the group of detached hills east of the school, and on the plain between these hills and the mountains there is a suggestion of the basal conglomerate at the proper horizon. These basal beds are shown again at the granite and porphyry hills, about 10 miles southeast of Mountain view, and at the east end of the Carrollton mountains, just west of the rifle range at Fort Sill, as well as on the south side of Signal mountain. No trace of any sedimentary rocks was found on the south side of the mountains west of this point.

*GERONIMO SERIES**

Rocks later than the Trenton were only seen southeast of Fort Sill. East of Cache creek and near the southeastern corner of the military reservation are certain limestone mesas known because of the presence of a number of asphaltum springs. This series of rocks include much shale and sandy limestone. It is characterized by low dips and extends some distance east of Fort Sill, on the Marlow trail. Near the base of the series the shales are interbedded with a conglomerate having a calcareous matrix and carrying large, 2-inch, rounded pebbles of granite, porphyry, and limestone. Unfortunately, no recognizable fossils were obtained from either the shales or the overlying limestones, and hence all evidence as to the age of the beds must be derived from the stratigraphy. They are manifestly later than the granite intrusion, and in composition and character resemble the known Paleozoic rocks of the region. They are earlier than the Red beds (Permian), as they pass under the latter. It is to be hoped that further study may be devoted to them.

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* In the absence of any more available name, this series is called after the famous Apache chief, who now lives as a prisoner of war at Fort Sill.

RED BEDS

The sandstones and shales of the Permian cover much of the prairie between the Washita river and the mountains. They were observed at many points in the course of the present work, but nothing with regard to them can be added to previous knowledge. They were nowhere seen to have been involved in the dynamic movements which have given a slight dip even to the Geronimo beds. They were seen quite near the mountains and wholly undisturbed. It would not be strange if at some point escaping observation they showed a certain amount of disturbance which might be traced to relatively recent and slight movements.

CRETACEOUS AND TERTIARY

Mr Robert T. Hill reports the former entirely absent from the mountains, and this accords entirely with our own observations. Comstock has assigned to the latter, under the name of Fort Sill beds, certain of the surface materials covering the intermontane pastures. There seems no good reason for this. The material is, as Vaughan remarks, lithologically similar to that which makes up the Red beds. Community of genesis probably accounts for this. The outwash from the mountains would be of much the same character, regardless of the time when it was deposited, and, while the matter may in its present condition be fully conceded to be one mainly of opinion, the author is inclined to treat these beds as of recent origin.

ALLUVIUM

Whatever may be the ultimate decision in regard to the beds just mentioned, it is perfectly certain that there is along the south side of the mountains a vast quantity of material which can not be considered to be other than recent. On West Cache creek beyond Quanas there are great beds of sand and recent conglomerate rising 50 feet above the present stream. The passes in the south range of mountains show great alluvial fans, which curiously enough in one or two instances seem to have choked the old passes and led to the capture of the headwaters of intermontane creeks by younger streams, which have cut new and sharp walled canyons through the south granite range. This outwash is far heavier on the south than the north side of the mountains, and boulders 6 to 8 inches in diameter were quite frequently found as much as 15 miles south of the mountains in such quantity as to preclude any hypothesis of their adventitious character. The suggestion is that there has been a marked differential rise to the north, and that any early limestone hills on the south have been buried by Permian and recent outwash.

Age of the Mountains

The preceding sketch of the geology has perhaps shown clearly enough what the conclusion must be as to the age of the mountains, but possibly a word or two of summary may not be out of place. It is evident that there was a pre-Cambrian land-mass of igneous rocks, and that over this was laid down an undisturbed sequence stretching from the Cambrian up to and including the Trenton. Then came the main upheaval and the intrusion of the granite. Around the edge of the new mountains the Geronimo series was laid down. The shearing and faulting of the granite and the presence of greenstone dikes cutting it, with the true though slight dip of the Geronimo beds, indicate later disturbances of lesser degree. Since the intrusion of the granite, however, the main history of the region has been one of vigorous and long continued erosion, through which the mechanical sediments of the Red beds and later deposits were prepared and distributed. That there was a notable interval of erosion between the intrusion of the granite and the Geronimo beds is shown by the presence of granite pebbles in the latter. Granite being intrusive, these pebbles could only be obtained after the erosion of a considerable amount of rock.

Report on the Fossils from the Wichita Mountains by Stuart Weller

The following determinations of the geologic horizons in the Wichita mountains have been made from a small collection of fossils submitted to me by Mr H. F. Bain, supplemented by a small collection secured by Professor R. D. Salisbury. The fossils are all poorly preserved and in almost every instance are imperfect or fragmentary, so that definite identification of the species is in most cases not practicable. They indicate, however, the presence of three distinct horizons, the lowest of which may be referred to the Cambrian and the two upper ones to the Ordovician.

Most of the material identified as Cambrian was collected at "Canyon Creek camp."* The species represented are as follows:

1. *Dikellocephalus?* sp. This is the most abundant species in the fauna and is placed in this genus with much hesitation. The glabella is usually all that is preserved. This portion of the head is rather strongly convex, subquadrangular in outline, with the lateral margins nearly parallel or slightly diverging anteriorly. The occipital furrow is strongly defined, with one much fainter glabella furrow situated at about one-third the distance from the occipital furrow to the anterior extremity of the head. The fixed cheeks are rather broad and moderately convex. In the largest and best preserved specimen the glabella is 19 millimeters long and 15 millimeters wide. The smallest specimen is 6 millimeters long and 4½ millimeters wide.
2. Free cheek of a trilobite, possibly belonging to the species referred to *Dikellocephalus.*
3. *Ptychoparia* sp. A single imperfect head shield.
4. Undetermined coiled gasteropod shell with an elaborate spire.
5. *Oboella?* sp. Two fragments.

A few specimens bearing the label "Fossils from conglomerate in sandstone east of granite dike"† also prove to be Cambrian, the species recognized being as follows:

1. *Ptychoparia*, sp. undetermined. A single well preserved cephalon.
2. Fragments of several trilobites too imperfectly preserved for identification.

All of these fossils would seem to indicate an Upper Cambrian horizon.

The fossils of the second horizon, the Calciferous of the Lower Ordovician, are for the most part from the limestone hills east of Rainy mountain. They were collected from several localities, but as they all seem to belong to a single general horizon, they will be listed all together.‡

1. Pygidium of trilobite. *Bathyurus?* sp.
2. Pygidium of undetermined trilobite.
3. *Cyrtoceras*, 1 or 2 species.
4. *Hormotoma* sp.
5. *Lophospira cassina*, Whitf. ?
6. One or two species of coiled gasteropods like *Holopea.*
7. *Raphistoma ? trochiscus*, Meek ?
8. *Ophileta complanata* var. ?
9. *Bucania* sp.
10. Two or three additional species of coiled gasteropods represented by fragments.
11. *Orthis* or *Strophomena* sp. Several undeterminate fragments belonging to one or the other of these genera.

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[*] Located in Blue Creek canyon, about 7 miles due north of mount Scott.

[†] Number 2 Blue Creek section.

[‡] Vaughan (Amer. Geologist, July, 1899, p. 49) collected *Rhaphistoma* and *Ophileta complanata* var. *nana*, as determined by Girty from this general locality.—H. F. B.

From the limestone of the Fort Sill quarry a few species were secured, as follows:*

1. *Ophileta* sp.
2. Fragments of trilobites, genus and species undetermined.

While all these fossils are in a very unsatisfactory condition for determination, there seems to be no doubt of their Calciferous or Chazy age.

The third horizon is that of the Trenton limestone. The only locality from which Trenton fossils have been examined is Rainy mountain. A few of these were submitted by Mr Bain, but most of them were collected by Professor Salisbury. The species recognized are as follows:

1. *Ceraurus*, sp. undetermined.
2. *Isotelus gigas* De Kay or *megistos* Locke. A single imperfect thoracic segment.
3. *Trinucleus concentricus* Eaton.
4. *Rhynchonella* sp.
5. *Orthis* (*Dalmanella*) *testudinaria* Dal.
6. *Rafinesquina alternata* Emm.
7. *Lingula rectilateralis* Emm.

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* From Fort Sill Vaughan reports *Paleophycus*, *Murchisonia*, *Cyrtoceras*, *Linguella* cf. *L. lamborni*, and *Asaphas*, from which it is suggested that the beds may be as late as the Trenton.—H. F. B.

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RELATIVE AGES OF THE KANAWHA AND ALLEGHENY SERIES AS INDICATED BY THE FOSSIL PLANTS*

BY DAVID WHITE

(*Read before the Society December 29, 1899*)

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INTRODUCTION

The two series or formations whose floras form the subject of this paper are the Allegheny and the Kanawha series. The first, which is typically developed in the Allegheny valley in western Pennsylvania, comprises what has generally been known as the "Lower Productive Coal Measures" in the northern bituminous fields. It lies between the Homewood sandstone, the upper member of the Pottsville formation, and the Mahoning sandstone, a massive sandstone which forms the lower member of the Conemaugh series or "Lower Barren Measures," consisting in part of red shales. The thickness of the Allegheny series in western Pennsylvania and northern West Virginia is usually about 300 feet.

The Kanawha series is typically exposed along the Great Kanawha river in southern West Virginia. Like the Allegheny series, this series, which will be more fully described on a later page, lies, generally speaking, between a sandstone group, including red shales, above and the great arenaceous series below, representing the Pottsville. It, likewise, is composed of shales, sandstones, limestones, etcetera, and is the most richly productive division of the Coal Measures in the Kanawha region. The Kanawha series develops a thickness of about 1,200 feet at its eastern outcrop.

On account of a similarity in the materials composing it, the similar position of the series as a whole in the general lithologic sequence, and the fact that the Allegheny series has been stratigraphically traced with great detail as far as central West Virginia, the Kanawha series has long been regarded as in toto the exact, though greatly expanded, equivalent of the Allegheny series. Furthermore, although the stratigraphic work in the geographic interval appears to have been somewhat fragmentary, even the much more numerous productive coals of the Kanawha have in recent years been declared to be either exactly identical with the respective Allegheny coals or, in view of the excessive number in the Virginian section, as merely splits of the same.

In view of these correlations, the paleontologist who examines the stratigraphic occurrence and distribution of the fossil plants in the middle Carboniferous along the Appalachian trough can not fail to be surprised at the great differences between the floras of the several groups of the

Allegheny series in the bituminous basins of Pennsylvania or northern West Virginia and those in the corresponding portions of the Kanawha series in southern West Virginia. It needs but a casual inspection of the floral succession in the southern Virginian district to show that the characteristic plants of the Allegheny series in the type region of Pennsylvania first appear only in the upper portion of the section along the Great Kanawha, the greater portion of the latter, including the most important coals, containing plants of manifestly earlier age.

The purpose of this paper is to present a preliminary statement of the general characters of the floras of the Allegheny series, the position of these floras in the Virginian section, and a characterization of the floras of the lower portion of the Kanawha series. Some general paleobotanic correlations will be given, together with a brief statement of the changes in stratigraphy and conditions of deposition which appear to be indicated by the distribution of the fossil plants.

Floras of the Allegheny Series

TYPE SECTIONS OF THE SERIES, AND ITS SUBDIVISIONS

The Allegheny series* or the Lower Productive Coal Measures† (XIII), as it has earlier and more commonly been known, is typically represented in the fourth, fifth, and sixth bituminous basins in the Allegheny valley of western Pennsylvania. It comprises approximately 300 feet of shales, sandstones, and coals, with several thin limestones, lying between the Homewood sandstone (conglomerate), the topmost member of the Pottsville formation (XII), and the Mahoning sandstone (locally conglomerate), which forms the base of the Conemaugh series or Lower Barren Measures (XIV). This series, which is comparatively uniform in this region, has been described and abundantly illustrated by columnar sections in the reports on Butler,‡ Armstrong,§ Clarion,|| Jefferson,¶ and Clearfield** counties, and in the Summary Final Report†† of the Second Geological Survey of Pennsylvania.

Typical sections are also described in Rogers's "Geology of Pennsylvania" and Doctor I. C. White's memoir "Stratigraphy of the Bituminous Coal Fields of Pennsylvania, Ohio, and West Virginia."‡‡ In the

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*Bull. U. S. Geol. Survey, no. 65, pp. 65, 99.

†Rogers: Geology of Pennsylvania, vol. i, part 1, p. 109. Sections described, vol. ii, part 1.

‡Second Geological Survey of Pennsylvania. Report of progress in the Beaver River district of the bituminous coal fields of western Pennsylvania, by I. C. White. Report Q, 1878. Northern townships of Butler county, by H. M. Chance. Report V, 1879.

§Report of progress in Armstrong county, by W. G. Platt. Report H^5, 1880.

||Report of progress in Clarion county, by H. M. Chance. Report VV, 1880.

¶Second report on Jefferson county, by W. G. Platt. Report H^6, 1881.

**Second report on Clearfield county, by H. M. Chance. Report H^7, 1884.

††Vol. iii, part 2, Harrisburg, 1883.

‡‡Bull. U. S. Geol. Survey, no. 65, 1891.

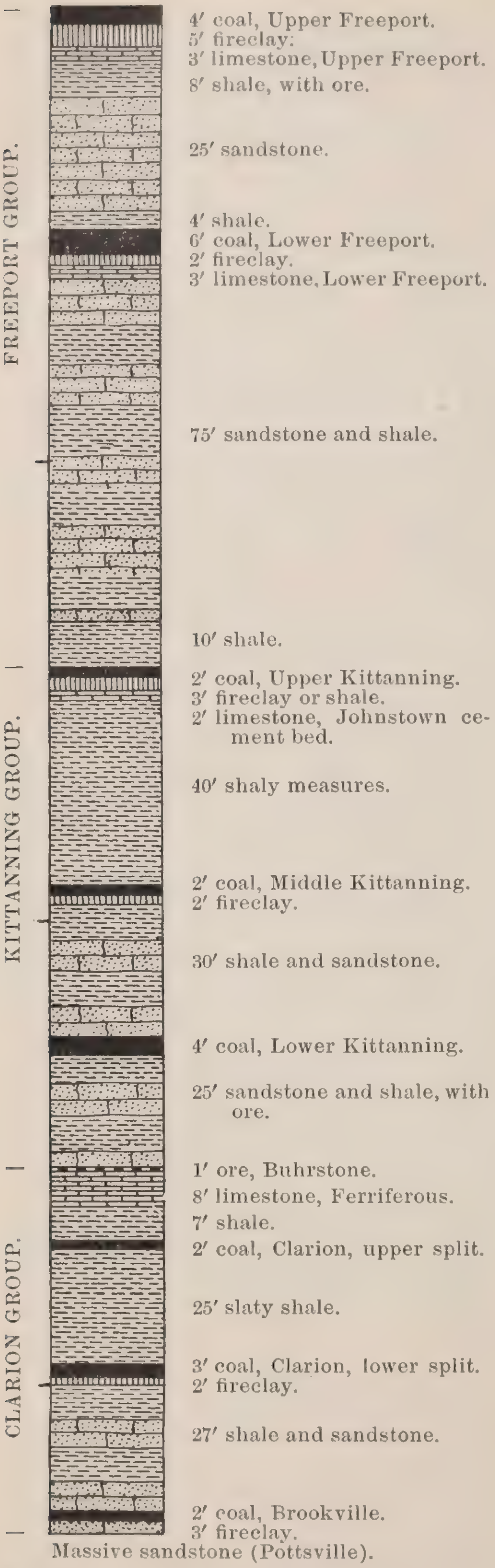

FIGURE 1.—*Generalized Section of the Allegheny Series in Clarion County, Pennsylvania.*

following pages reference will frequently be made to the very useful and excellent work last mentioned.

The general composition of the Allegheny series in northwestern Pennsylvania is indicated in the following section, figure 1, prepared by Mr Chance to show the sequence in Clarion county.* It differs from the sections in Jefferson, southern Armstrong, or Butler counties chiefly by the development of the Scrubgrass coal and the concomitant expansion of the interval between the Brookville bed and the "ferriferous limestone."†

CLARION GROUP

Plant beds of the group.—The interval embracing the lower portion of the Allegheny series, from the top of the Homewood sandstone (Pottsville formation) up to the top of the "Ferriferous limestone," is known ‡ as the Clarion group. The ordinary thickness of this group is about 70 or 75 feet in the Allegheny valley. Two coals—sometimes three or more, two of which are locally workable—are usually present in this section.

In the Clarion group of western Pennsylvania determinable fossil plants are generally very rare, most of the scarce material from this region being badly macerated and abraded. Nevertheless, specimens have been collected from the roof of the Brookville coal, which usually occurs within a few feet of or almost on the top of the Pottsville formation, at Port Barnett, near Brookville (Br.), and from the roof shales of the Clarion coal at Somerville (Som.), near the Clarion county line. Fossil plants occur in this group in Butler and Mercer counties, where they have been collected at Grove City (G. C.), Pardoe (Par.), and Filer (Fil.), from above the "Pardoe" coal. This coal is regarded by Doctor I. C. White as equivalent to the Brookville coal, though it is thought that it possibly represents the Clarion coal. Its reference to the Clarion group is, however, certain.

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* Report of Progress, Second Geol. Survey Penn., VV, p. 32, Fig. 2. Reproduced by Doctor I. C. White: Bull. U. S. Geol. Survey, no. 65, p. 105, fig. 55.

† Other typical sections for these counties are quoted in Bull. U. S. Geol. Survey, no. 65, pp. 104–111; and summary final report, Second Geol. Survey Penna., vol. iii, part 2, pp. 449, 450, etc.

‡ Report of Progress, Second Geol. Survey Pa., VV., p. 41, 49.

Plants of the Clarion group.—For the sake of economy of space, the species collected from the relatively small stratigraphic interval included in the Clarion group may be combined in one list, from which the plants of each horizon may be separated by referring to the abbreviations given above. The identifications are the result of a preliminary study and are, as such, subject to revision.

Name.	Locality.
Mariopteris cf. *aspera* Brongn	Fil.
Pecopteris villosa Brongn.*	Fil., Som.
" cf. *vestita* Lx.*	Br.
Alethopteris serlii (Brongn.) Goepp	G. C.
Neuropteris desorii Lx.*	Fil.
" *rarinervis* Bunby *	G. C., Par.
" *ovata* Hoffm.*	Br., Fil., G. C., Som.
" *vermicularis* Lx.*	Som.
" *scheuchzeri* Hoffm.*	Br., Fil., G. C., Som.
Caulopteris sp	Fil.
Annularia stellata (Schloth.) Wood *	Fil.
" *sphenophylloides* (Zenk.) Gutb.*	Par.
Sphenophyllum emarginatum Brongn.*	Br.
Lycopodites meekii Lx	Par.
Lepidodendron dichotomum Sternb	Fil.
" cf. *andrewsi* Lx.*	Par.
" *clypeatum* Lx	Fil.
Lepidostrobus geinitzii Schimp.*	Fil.
Lepidophyllum lanceolatum L. & H.*	Par., Som.
Polysporia sp	Fil.
Sigillaria cf. *brardii* Brongn	Fil.
" (*Rhytidolepis*) sp	Fil.
Cordaites lacoei Lx. ?*	Fil.
Cardiocarpon sp	Fil., G. C.
Rhabdocarpos multistriatus (Sternb.) Lx.*	Fil.

The species in the above list comprise a flora representative of the lower portion of the Allegheny series. The forms marked by the asterisk (*) are characteristic of the post-Pottsville terranes in the Pennsylvanian sections.

KITTANNING GROUP

Plant beds of the group.—That portion of the series extending from the top of the Ferriferous limestone to the top of the Upper Kittanning coal has been termed * the Kittanning group. In the typical region this group embraces about 120 feet, including the three Kittanning coals, the middle one of which is very rarely of workable thickness. That portion in the vicinity of the Lower and Middle Kittanning coals is usually largely occupied by dark shales, often black and fissile, whose more common fossils are marine or brackish water mollusks. Plant remains, except fragments of the more indestructible tissue, are generally very rare and very poorly preserved. The uppermost portion of the series is more arenaceous and phytiferous.

Since the plants of the shales forming the immediate roof of the Upper Kittanning coal mark the date of the latter, I include that flora in the same group. From the shales accompanying the Lower Kittanning coal, or the "Dagus" coal, which is generally regarded as equivalent thereto, fossil plants have been collected near Snowshoe (Sn.), Center county, the Dagus mines, Elk county, and Hommers (Hom.), in Clearfield county. The Miller coal, from the roof of which plants were collected at Trout Run (T. R.), in Cambria county, is supposed to represent the same horizon. Plants have been found at the horizon of the Middle Kittanning near Logansport (Log.), Armstrong county, and along the railway between Powelton and Electric (El.), in Clearfield county. The environing shales of this coal generally contain little but stem and Lycopodineous leaf fragments. The roof shales of the Upper Kittanning are, however, frequently the matrix of well preserved plant remains. Fossils have been collected at this level at Kittanning (Kit.), and Kelleys station (K. S.), Armstrong county; Euclid (Eu.), Butler county; Fairmount (Fair.), Clarion county, and along Toby creek (T. C.), in Clearfield county. The very rich flora from Cannelton (Can.), Beaver county, described in "The Coal Flora," by Lesquereux, is said by Doctor I. C. White † to have come from the floor of the Darlington coal, which is correlated by Doctor White with the Upper Kittanning coal.

Species from the Kittanning group.—In the following list of species from the Kittanning group those marked with the asterisk (*) are, so far as is known, characteristic of the post-Pottsville terranes in the Pennsylvanian sections. A large portion of the species from Cannelton are cited on the authority of Professor Lesquereux.

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* Op. cit., p. 33.

† Report of Progress, Second Geol. Survey Pa., Q, pp. 51, 54.

Name.	Locality.
Rhacopteris elegans (Ett.) Schimp. [Lesq.]†	Can.
Pseudopecopteris macilenta (L. and H.) Lx. typical.	Can.
“ *squamosa* (Lx.)*	T. C., Can.
“ *hispida* Lx.	Can.
“ *nummularia* (Gutb.) Lx.*	Can.
“ *plukenetii* (Schloth.) Lx.* [Lesq.].	Can.
Mariopteris sillimanni (Brongn.)*	T. C., Can.
“ *nervosa* (Brongn.) Zeill.	Sn., Can.
“ *newberryi* (Lx.)*	Can.
Sphenopteris stipulata Gutb. [Lesq.]	Can.
“ *canneltoni* D. W.*	Can.
“ *subalata* Weiss* [Lesq.]	Can.
“ *chærophylloides* (Brongn.) Presl*	Can.
“ *goniopteroides* Lx.? *	El.
Aloiopteris winslovii D. W.*	Sn., T. R., Can.
“ *erosa* (Gutb.) ?	Can.
Pecopteris dentata Brongn.*	Sn., T. R., Can.
Neuropteris rarinervis Bunby.*	Can.
“ *ovata* Hoffm.*	Kit., Log., En., Fair., Sn., Hom., T. R., El., T. C., Can.
“ *fimbriata* Lx.*	Sn., Can.
“ *vermicularis* Lx.*	K. S., El., T. C., Can.
“ *aspera* Lx.	Can.
“ *scheuchzeri* Hoffm.*	Kit., T. C., En., K. S., Fair., Sn., T. R., Can.
“ *clarksoni* Lx.*	K. S., Can.
“ *oblongifolia* Lx.*	Can.
“ *rogersi* Lx.*	Can.
“ *agassizi* Lx.* [Lesq.]	Can.
“ *crenulata* Brongn ? * [Lesq.]	Can.
Linopteris obliqua (Bunby.) Pot*	Fair., El., T. C., Eu., Can.
Odontopteris cornuta Lx.*	Can.
Caulopteris mansfieldi Lx.*	Can.
“ *obtecta* Lx.*	Can.
“ *cistii* (Brongn.) Presl*	Can.
Rhachiopteris squamosa Lx.	Can.
Aphlebia adnascens (L. and H.) Presl.	Can.
“ *cornuta* (Lx.) [Lesq.]	Can.
“ *filiciformis* (Gutb.) [Lesq.]	Can.
“ *trichomanoides* (Goepp.) [Lesq.].	Can.
“ *tricoidea* (Lx.) [Lesq.]	Can.
“ *thalliformis* (Lx.)	Can.

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† “Lesq.” in brackets indicates identification or interpretation of the species by Professor Lesquereux.

Name.	Locality.
Calamites ramosus Artis	Can.
“ *suckowii* Brongn	Sn., Can.
“ *approximatus* Brongn	Can.
Asterophyllites equisetiformis (Schloth.) Brongn.*	Can.
Annularia ramosa Weiss	Can.
“ *stellata* (Schloth.) Wood.*	T. C., Can.
“ *sphenophylloides* (Zenk.) Gutb.*	T. C., Sn., T. R., Can.
Calamostachys brevifolius Lx	Can.
Sphenophyllum majus Bronn*	Sn., Hom., Can.
“ *emarginatum* Brongn.*	K. S., Sn., T. R., T. C., El., Can.
“ *schlotheimii* Brongn.* [Lesq.]	Can.
Lepidodendron cf. *brittsii* Lx.*	Kit.
“ *dichotomum* Sternb	Log., Fair., Eu., Can.
“ *aculeatum* Sternb	Can.
“ *modulatum* Lx.*	Sn., Dag., Can.
“ *rigens* Lx	Can.
Lepidophloios auriculatus Lx.*	Can.
“ *dilatatus* Lx.*	Can.
Halonia mansfieldi Lx.*	Can.
Lepidostrobus cf. *variabilis* L. and H	Sn., Hom., Can.
“ *butleri* Lx.*	Can.
“ *goldenbergii* Schimp.* [Lesq.]	Sn., Can.
“ *spectabilis* Lx.*	Can.
Lepidophyllum cultriforme Lx.*	Can.
“ *foliaceum* Lx	El.?, En.?, Kit., Can.
“ *lanceolatum* L. and H.*	Can.
“ *mansfieldi* Lx.*	Can.
Lepidocystis truncatus Lx	Can.
“ *vesicularis* Lx	Can.
Sigillaria camptotænia Wood*	T. C., Can.
“ *tesselata* (Steinh.) Brongn. [Lesq.]	Sn.
Tæniophyllum brevifolium Lx.*	Can.
“ *deflexum* Lx.*	Can.
“ *decurrens* Lx.*	Can.
Desmiophyllum gracile Lx	Can.
Dolerophyllocarpum pennsylvanicum Dn.*	Can.
Cordaites borassifolius (Sternb.) Ung. [Lesq.]	Can.
“ *mansfieldi* Lx.*	Can.
“ *serpens* Lx.*	Can.
“ *costatus* Lx.*	Can.
“ *radiatus* Lx.*	Can.
Cordaïstrobus grand'euryi Lx.*	Can.
Cordianthus ovatus Lx.*	Can.
“ *mansfieldi* Lx.*	Can.
“ *costatus* Lx.*	Can.
Cordaicarpon gutbieri Gein.*	Sn., Can.
“ *ovatum* Gr'Ey.* [Lesq.]	Can.

Name.	Locality.
Cordaicarpon cinctum Lx.*	Can.
“ *costatum* Lx.*	Can.
Cardiocarpon marginatum (Art.) Gein.*	Can.
“ *ellipticum* (Sternb.) Lx.*	Can.
“ *pusillum* Lx.	Can.
Trigonocarpum adamsii Lx.*	Can.
“ *menzelianum* Goepp. & Berg. [Lesq.]	Can.
“ *grande* Lx.*	Sn., El., Can.
“ *schultzianum* Goepp. & Berg. [Lesq.]	Can.
Rhabdocarpos arcuatus Lx.	Can.
“ *subglobosus* Lx	Can.
“ *tenax* Lx.*	Can.
“ *inflatus* Lx.	Can.
“ *beinertianus* Goepp. and Berg.	Can.
“ *jacksonensis* Lx.* [Lesq.]	Can.
“ (*Pachytesta*) *mansfieldi* Lx.*	Can.
“ *abnormalis* Lx	Can.
“ *mammillatus* Lx.*	Can.
Dicranophyllum dichotomum Lx.*	Can.
“ *dimorphum* Lx.*	Can.
Carpolithes cerasiformis Presl* [Lesq.]	Can.
“ *minimus* Sternb	Can.
“ *perpusillus* Lx	Can.

FREEPORT GROUP

Plant beds and localities.—The term “Freeport group” has been applied* to the remaining upper portion of the Allegheny series, including the two Freeport coals, and extending from the top of the Upper Kittanning coal to the top of the Upper Freeport coal. This division of the series is subject to considerable variation, chiefly by the expansion of the two Freeport sandstones; but in Clarion county it appears to average about 130 feet in thickness.

In considering the flora accompanying the Upper Freeport coal I include the plants in the roof of that coal, though, strictly speaking, the shales belong to the base of the Mahoning sandstone, as that name is customarily, but often inappropriately, applied. From the roof of the Lower Freeport coal collections of plants have been made at Big Soldier run (R.), near Reynoldsville, Elk run (E. R.), and Horatio (H.), near Punxsutawney, in Jefferson county, and at the Dubois shaft (Dub.) and the Shawmut mines (Shaw.), in Clearfield county.

The roof of the Upper Freeport coal contains good plant fossils at the Brackenbush mine (Brack.), about 2 miles east of Freeport, at Shenley

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* Report of Progress, Second Geol. Survey Pa., VV, pp. 33, 34.

(Sh.), at the Gilpin (Gil.), and Haddon (Had.) mines, near Bagdad, and at Pine run, near Vandergrift (Van.), all in the vicinity of Freeport, Armstrong county, and at Coal Glen (C. G.), in Jefferson county.

Species from the Freeport group.—As in the preceding lists, the plants from each horizon may be separated by grouping the species according to the localities as indicated in the abbreviated forms therein given.

Name.	Locality.
Mariopteris nervosa (Brongn.) Zeill	Shaw., Hor., Gil., E. R.
“ *sillimanni* (Brongn.) D. W	R., Dub., Hor.
Pseudopecopteris squamosa (Lx.) (large)	Dub., Sh.
Sphenopteris pseudomurrayana Lx.?	Hor., E. R.
“ cf. *mixta* Schimp	Dub.
Pecopteris dentata Brongn	Hor.
“ *unita* Brongn.	R., C. G.
“ *squamosa* Lx	
“ *villosa* Brongn.?	Hor., Dub., Gil., Sh., Had., E. R., Gil., R., Shaw.
“ *pennæformis* Brongn. [Lesq.]	Sh., C. G.
“ *oreopteridia* (Schloth.) Brongn	Hor., Dub., Gil., Sh., E. R., R., Shaw.
“ *polymorpha* Brongn	Hor., Dub., Had., E. R.
“ *pteroides* Brongn.?	Dub.
Alethopteris serlii (Brongn.) Goepp	Hor., Gil.
“ *pennsylvanica* Lx	C. G.
Callipteridium neuropteroides Lx.?	Dub.
Neuropteris ovata Hoffm	Brack., Gil., Sh., Hor., E. R., Dub., R., Shaw.
“ *clarksoni* Lx	Hor.
“ *scheuchzeri* Hoffm	Had., Brack., Gil., Sh., Hor., E. R., Shaw., P., Dub., C. G., R.
Linopteris obliqua (Bunby) Pot	Hor., E. R., R.
Calamites cistii Brongn	Sh., Hor.
“ sp	Dub.
Calamitina sp	R., Hor.
Asterophyllites equisetiformis (Schloth.) Brongn	Hor., E. R., Dub.
Annularia stellata (Schloth.) Wood	Had., Hor.
“ *sphenophylloides* (Zenk.) Gutb	Hor.
Sphenophyllum emarginatum Brongn	Brack., Gil., R., Hor., E. R., Dub., C. G.
Lepidodendron lanceolatum Lx.?	Dub.
“ *dichotomum* Sternb.?	Van., Sh., R., Hor.
“ *modulatum* Lx	Hor., Dub.
Lepidostrobus cf. *variabilis* L. and H	Had., Van.
“ *geinitzii* Schimp.?	Hor.
Lepidophyllum cultriforme Lx	R.
“ *hastatum* Lx	Sh.
“ *lanceolatum* L. and H	Hor.

Name.	Locality.
Sigillaria camptotænia Wood	R., Hor.
Cordaites sp	
Rhabdocarpos (*Pachytesta*) cf. *mansfieldi* Lx.	Hor.

GENERAL CHARACTERISTICS OF THE ALLEGHENY FLORAS

As compared with the floras of the Pottsville formation, the floras of the Allegheny series are characterized by a marked difference in the fern species, the Annulariæ and the Sphenophylleæ. Of most practical importance, however, are *Neuropteris ovata*, *N. scheuchzeri*, and *Sphenophyllum emarginatum.* In fact, these species in typical forms are practically omnipresent in the Allegheny series, and it is seldom that one of these is lacking even in small and hastily made collections. *Neuropteris scheuchzeri*, in the ordinary form described by Professor Lesquereux as *N. hirsuta*, is usually most abundant. *Annularia stellata* and *A. sphenophylloides* are nearly always present in any considerable quantity of material, even at so low a level as the roof of the Brookville coal.

Of the Sphenopterids the most common of the typical Allegheny species are *Sphenopteris mixta*, *S. pinnatifida*, *S. hymenophylloides*, as identified by Professor Lesquereux, *S. pseudomurrayana*, *S. chærophylloides*, and *S. brittsii.* The more common species of *Pseudopecopteris* are *P. obtusiloba* and *P. squamosa.* The latter is generally represented in the lower terranes by the small form described as *Sphenopteris squamosa*, which in later beds passes into the form known as *Pseudopecopteris anceps* Lx., or *Sphenopteris neuropteroides* Boul. The characteristic types of *Mariopteris* are those belonging to the *ovata-cordata* group, represented by *Mariopteris sillimanni.* *Mariopteris nervosa*, or *M. muricata* var. *nervosa*, is typically common in the Allegheny series, though it occurs also in the uppermost beds of the Pottsville formation. *Mariopteris newberryi* appears to be characteristic of the Kittanning group.

A conspicuous feature in the Allegheny floras is the development of the Pecopterids. The genus *Pecopteris*, which, as *P. serrulata* Hartt, makes its appearance in the Upper (Sewell division) Pottsville of the Appalachian trough and which seems to be represented by but one or two other small species or forms of the villous group in the topmost beds of the Pottsville, is present as *P. dentata* and the species always doubtfully identified by Professor Lesquereux as *P. villosa* Brongn., or *P. vestita* in the lower beds of the Allegheny series. Very soon, however, we find representatives of the Goniopteroid group, such as *P. unita* and *P. emarginata*, as well as the larger villous types of the genus, while in the Freeport group the large Neuropteroid forms, such as *P. polymorpha* and *P. pteroides*, are added to the slightly earlier *P. oreopteridia* and *P. miltoni.*

Here, too, occasional representatives of the *Pecopteris arborescens* group, *P. arborescens*, *P. hemitelioides*, *P. cyathea*, or *P. lesquereuxii* are found. The writer is not certain of the presence of the true *P. arborescens* at any point below the Freeport group.

The post-Pottsville floras of the Pennsylvania sections are also well marked by their Neuropteroid elements. *Neuropteris vermicularis*, generally characteristic of the lower group of the Allegheny series, is usually accompanied by *N. rarinervis*, while such forms as *N. fimbriata*, *N. clarksoni*, *N. griffithii*, or *N. crenulata*, usually at higher levels, are readily recognized. The ubiquitous *Neuropteris ovata* and *N. scheuchzeri* also become somewhat modified in the higher beds, the pinnules of the former developing larger and less broadly attached, while those of the latter are more lingulate and larger. The lingulate and the cuneate-lobed types of *Odontopteris*, as well as the entire genus *Linopteris* (*Dictyopteris*), typified in *Dictyopteris obliqua*, appear to be wholly unknown below the Allegheny series in the Pennsylvanian section; so with the broad, obtuse-pinnuled species of *Callipteridium*.

The Calamarian stems and the trunks of Lepidodendron and Sigillaria are of very inferior stratigraphic value as compared to the ferns. However, in contrast to the Pottsville flora, the Allegheny flora is characterized by the presence of *Asterophyllites equisetiformis*, *Annularia stellata*, and *A. sphenophylloides*. The leaves of the first and last named species are generally rather small in the lower group, but rapidly develop to the typical proportions. *Sphenophyllum majus* and *S. emarginatum* are both characteristic of the post-Pottsville beds. The last named species, which in this country seems to have been confused with *S. schlotheimii*, is generally omnipresent above the Homewood sandstone or the "Buck Mountain conglomerate," while, on the other hand, below the latter we find the very narrow, slender, and very lax form described by Professor Lesquereux, from the upper Pottsville, as *S. saxifragæfolium*. Even among the Lepidophytes we find such distinctive and well known types as *Lepidodendron modulatum*, the group of large Lepidostrobi, such as *Lepidostrobus spectabilis*, *Lepidophyllum oblongifolium*, and *L. ovatifolium*, and the *Sigillaria camptotænia* to be peculiar to the Allegheny series or higher beds. Of the great diversity of gymnospermous fruits, the large *Cordaicarpa*, the large, broad *Pachytesta*, types of *Rhabdocarpos*, as well as a number of small fruits, such as *R. mamillatus* and *Carpolithes ellipticus*, are evidence of a terrane as high as or higher than the Allegheny series. It must not be inferred from the above that the Allegheny series is marked by the introduction of new types rather than by the extinction of Pottsville forms. The Pottsville is characterized by a moderately rich flora, the greater part of whose fern elements and nearly all of whose Annularian and Sphenophyllean elements are not known in the Allegheny series.

FLORAS OF THE KANAWHA SERIES

TYPICAL REGION AND THICKNESS OF THE FORMATION

The "Kanawha series" is typically exposed along the Great Kanawha river in southern West Virginia. Terranes of this series appear in the gorge of that river from a point above Fayette station, where it caps the high knobs, to near Charleston, 50 miles below, where it goes beneath water level. For 35 miles the steep slopes of the valley lie almost entirely in the Kanawha formation. This formation, which is largely arenaceous, includes several thin calcareous beds and an uncertain, though considerable, number of workable coals. From a maximum thickness of approximately 1,200 feet at its eastern outcrop it thins to about 650 feet before passing under at Charleston.* Borings to the westward indicate a still further reduction in thickness.

The general constitution of the series is indicated by the accompanying sections. The first, figure 2, is a carefully prepared section published by Doctor I. C. White in his memoir, "Stratigraphy of the Bituminous Coal Field in Pennsylvania, Ohio, and West Virginia."† It shows the principal coals in the lower portion of the section as well as the upper limit of the series as defined by him. The Pennsylvanian nomenclature of the coals is that applied by Doctor White.

The second section,‡ figure 3, illustrates at once the relations of the upper coals in the series, as well as the lower coals developed farther down the Kanawha, in the vicinity of Dego. It has not yet been found practicable to trace all of the important coals from one point to the other. The equivalents of even the lower coals shown in the Cedar Grove sections are not definitely known in the Armstrong section.

DIVISION OF THE KANAWHA COALS INTO TWO GROUPS

COMPOSITION OF THE GROUPS

In their discussion of the type section of the Kanawha formation Messrs Campbell and Mendenhall § have found it most convenient to divide the coals of the formation into two groups.

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*I. C. White in Bull. U. S. Geol. Survey, no. 65, p. 138.

†Loc. cit., p. 138, fig. 113.

‡Presented by the courtesy of Mr Oscar A. Veazey, who has given great attention to the Kanawha formation in this region.

§Geologic section along the New and Kanawha rivers in West Virginia. Seventeenth Ann. Rept. U. S. Geol. Survey, part 2, 1896, pp. 473–511, pls. xxxix–xlix.

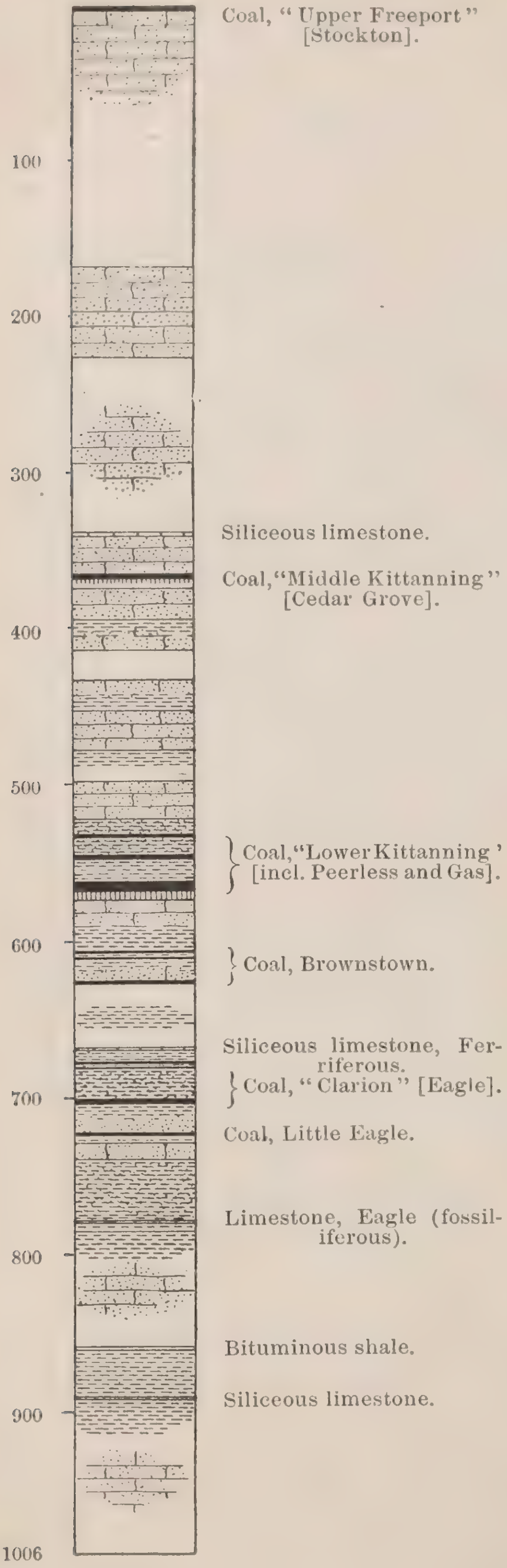
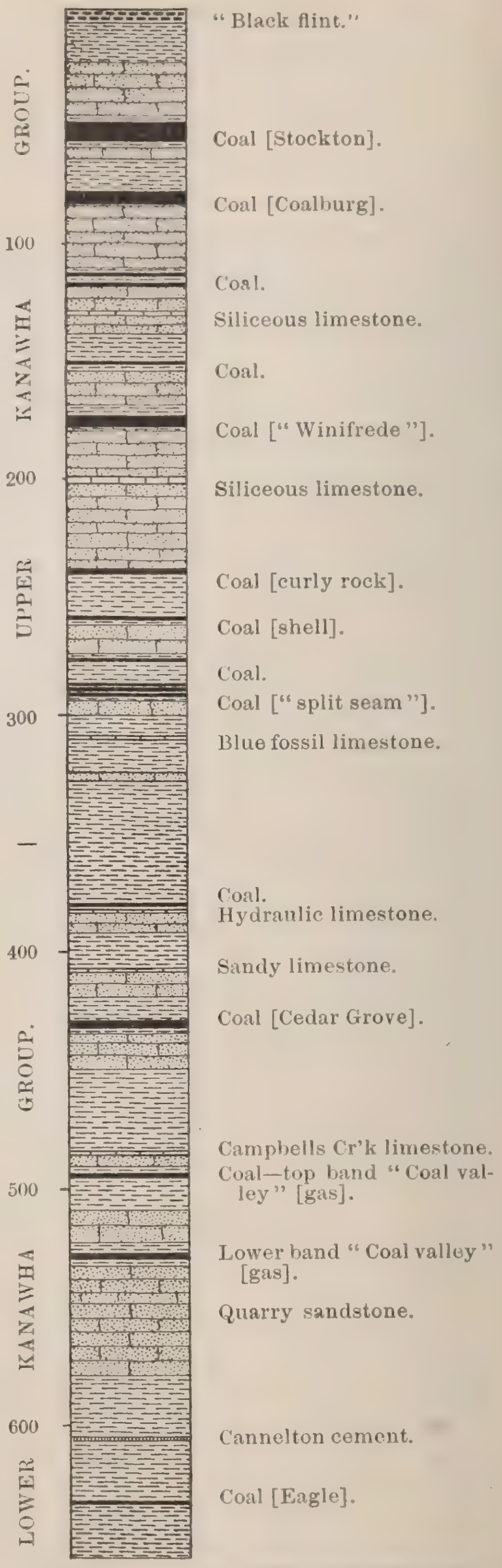

Coal, "Upper Freeport" [Stockton].
100
200
300
Siliceous limestone.
Coal, "Middle Kittanning" [Cedar Grove].
400
500
Coal, "Lower Kittanning' [incl. Peerless and Gas].
600
Coal, Brownstown.
Siliceous limestone, Ferriferous.
Coal, "Clarion" [Eagle].
700
Coal, Little Eagle.
Limestone, Eagle (fossiliferous).
800
Bituminous shale.
Siliceous limestone.
900
1006

Figure 2.—*Section of the Kanawha Series at the mouth of Armstrong Creek, on the Great Kanawha River, West Virginia.*



(Concealed to top of Pottsville formation.)

Figure 3.—*Section of the Kanawha Formation in the Vicinity of Dego, West Virginia.*

> "The lower group includes the Ansted, Eagle, Gas, Cedar Grove, Tunnel, Peerless, Brownstown, Campbells creek, and the associated thin seams. The principal coal seams of the upper group are the Stockton or Crown Hill, the Coalburg, and the Kanawha Mining or Winifrede seams. Between these two groups are about 300 feet of practically barren strata."

The correlations of the developments in the upper group have led to little or no differences of opinion, the Winifrede coal being generally regarded as identical with the Kanawha mining seam. With reference to the identities of the coals in the lower division, there is, however, some difference of opinion, as may be seen by a consultation of the two memoirs just cited. With these differences we have at present little to do, since in this paper the floras are treated only in the most general way and from a broad point of view. I shall therefore not here consider the correlation of the individual coals, though I may add that the final systematic treatment of the fossil plants of the several horizons promises to throw light on a number of points now in dispute.

So far as concerns the stratigraphic positions of the coals in the lower group, it is sufficient for present purposes to state that the Eagle, the lowest workable coal, is about 330 feet above the base of the formation as that boundary has, largely on lithologic evidence, been traced. The Gas coal is about 155 feet above the Eagle coal. There is doubt as to the equivalence of the Gas coal, as well as to the relations of the other coals of the lower group to it. For paleontologic reasons, I am slightly disposed to regard the Tunnel coal mined at Cedar Grove as identical with the Gas coal. It certainly can not be far from the same stratigraphic level. The Cedar Grove coal is but 125 feet above the Tunnel bed. Twenty-five feet above the Cedar Grove bed another 1-foot coal is found. It is important to note that a slope from the latter to the Tunnel coal cuts no less than five coals, each of which is from 1 to 4 feet in thickness. The painstaking stratigraphic studies carried on by Messrs Campbell and Mendenhall show * that within the interval of 140 feet traversed by this slope there must fall the horizons of the Gas, Peerless, Brownstown, and Campbells Creek coals, as well as the Cedar Grove and Tunnel beds.

Within the relatively short period represented by the deposition of 140 feet of the formation no marked floral changes are to be expected, and for the purposes of broad correlation the local floras may be combined. I may add, however, that on account of certain peculiarities and minor phases of the local floras I am inclined to place the roof shales of the Peerless coal not far from the level of the Gas coal or the Tunnel

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* Op. cit., p. 502.

bed. To the interval between the latter and the Cedar Grove I would refer the coals mined at Ansted and Cotton hill. They are perhaps most closely related paleontologically to the Cedar Grove coal.

FLORAS OF THE LOWER GROUP OF COALS

Localities.—The roof shales of the principal coals in the lower group along the Kanawha river usually contain abundant carbonized plant remains which are beautifully impressed. As representative of the floras of the principal horizons of the lower group of coals, collections will be cited from the following localities* along the Kanawha river:

1. Six feet below the Eagle coal at Crescent (Cresc. E.), and from the roof of the Eagle coal at the Eagle mine (Eag. E.), and at Saint Clair (St. C. E.).
2. Five feet below the Gas coal at Forest Hill (F. H. G.) mine near Edgewater; also from the roof of the same coal at the Diamond mine (Diam. G.) one mile below mount Carbon, at Crescent (Cr. G.), and two mines near the mouth of Morris creek (M. C. G.).
3. Tunnel coal in slope at Cedar grove (C. G. T.), and at the mouth of Kelleys creek (K. C. T.).
4. Roof shales of the Peerless coal at Peerless (P. P.); from a drift one-half mile below Cedar grove (C. G. P.); Little fork of Slaughter creek (Sl. P.); the Black Diamond mine near Lewiston (B. D. P.); shaft at the Monarch mine (Mon. P.) near Peabody; as probably coming not far from the same horizon we may also include the fossils from the roof shales at Handley (Hand.), and the roadside near the incline at the Black Cat mine (B. C.).
5. Roof of the Cedar Grove coal at Cedar Grove (C. G. C.); Kelleys creek, below the mouth of Hurricane branch (H. C. G.); the Big Mountain mine near the mouth of Kelleys creek (K. C. G.); East Bank (E. C. G.); Black Cat (Bl. C. G.), and from the roof of a coal supposed to be the Cedar Grove seam at the Riverside mine opposite Crown Hill (R. C. G.).
6. The coal mined at Ansted (Anst.) and Cotton Hill (C. H.) also belongs to the lower group.

The greater portion of the ferns accompanying the lower group of the Kanawha coals consists either of species not yet described from our American Coal Measures or of phases and varieties clearly different from the familiar or typical forms. A part of the flora is composed of the survivors of the floras in the upper portion of the Pottsville; that is, Sewell and Fayette formations.† As neither the latter nor the floras of the Kanawha formation are yet completely elaborated systematically, the identifications recorded below must be considered as tentative or often comparative and subject to revision in the full systematic report on the floras of the two formations which is now in preparation.

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* In this paper only the localities typical of the coal-bearing horizons will be reviewed.

† Campbell and Mendenhall, op. cit., pp. 494, 497.

Plants at the horizon of the Eagle coal.—As indicating the frequent occurrence of the Pottsville survivors, or of modified forms of Pottsville species, as high as the Eagle coal in the Kanawha formation, I have designated such species with an asterisk in the following list † of plants from the horizon of that coal:

Name.	Locality.
Eremopteris n. sp.*	Eag. E.
“ cf. *lincolniana* D. W.*	St. C. E.
Pseudopecopteris trifoliolata (Artis)	Cresc. E., Eag. E., St. C. E.
Mariopteris muricata (Schloth.) Zeill.*	Eag. E., St. C. E.
“ *nervosa* (Brongn.) Zeill	Eag. E.
“ *acuta* (Brongn.) Zeill	Cresc. E., Eag. E., St. C. E.
“ *inflata* (Newb.)*	Eag. E.
Sphenopteris spinosa Goepp.*	Eag. E., St. C. E.
“ *furcata* Brongn.* (small)	Cresc. E.
“ *linkii* Goepp.*	Cresc. E.
“ cf. *dubuissonis* Brongn. [Lesq.]	St. C. E.
“ *tracyana* Lx.*?	Eag. E.
“ *schatzlarensis* Stur?	Cresc. E., St. C. E.
“ cf. *microcarpa* Lx.*	Eag. E., St. C. E.
Pecopteris sp. cf. *integra* Andrä	Cresc. E.
Alethopteris decurrens Artis	Cresc. E.
“ *serlii* (Brongn.) Goepp	Eag. E., St. C. E.
Neuropteris cf. *zeilleri* Pot.*	Cresc. E.
“ cf. *flexuosa* Sternb.‡	Eag. E., St. C. E.
Calamites ramosus Artis	St. C. E.
Asterophyllites minutus Andr.*	Cresc. E.
“ *rigidus* Sternb	Eag. E.
Annularia ramosa Weiss	Cresc. E., St. C. E.
“ *acicularis* (Dn.) Ren.*	Cresc. E., Eag. E.
Calamostachys ramosus Weiss	St. C. E.
Sphenophyllum furcatum Lx.* (slender)	Cresc. E., Eag. E.
“ *cuneifolium* (Sternb.) Zeill. (lax form)*	Eag. E., St. C. E.
Lepidodendron sp. cf. *dichotomum* Sternb. ?	Cresc. E., Eag. E.
“ *obovatum* Sternb.	Eag. E.
Bothrodendron n. sp.*	St. C. E.
Lepidostrobus variabilis L. & H	Eag. E., St. C. E.
Lepidophyllum campbellianum Lx.*	Eag. E., St. C. E.
Rhabdocarpos sulcatus Goepp. and Bein	Eag. E.

A comparison of the Eagle flora with the flora of the Clarion group (p. 149) shows but a very small percentage of identical elements in common. Most important is the total absence at or below the Eagle horizon in the Kanawha formation of the everywhere common and characteristic species which, in the Allegheny series, range from the Brookville coal upward. This disparity is the more striking since the Eagle coal, which has been correlated with the Clarion coal of northwestern Pennsylvania, is over 300 feet above the top of the Pottsville, as the upper boundary of the latter formation has by all geologists been located, along the Kanawha river. It may here be remarked that between the Pottsville series (Fayette, Sewell, Raleigh, etcetera, formations) of southern West Virginia and the Allegheny series in the typical region there is hardly a distinct fern species in common,[*] although, as will later be seen, identical or modified forms of species in the Fayette and Sewell formations penetrate the entire lower group on the Kanawha. The plants from horizons below the Eagle coal, as, for example, the so-called "black marble" at Ansted,[†] which is correlated by local experts with the Eagle limestone, or in the beds at the mouth of Paint creek, show a much stronger impregnation of Upper Pottsville types. On the other hand, by the time we rise to the Cedar Grove horizon the Virginian Pottsville fern types have either disappeared almost completely or they are represented only by well marked modifications.

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† Although the list is hardly complete, it shows approximately the proportions of the zonal elements.

‡ The plant in hand approaches very closely to the Old World type, though it is specifically different from the forms from the Anthracite and Northern bituminous basins identified under the same name.

Plants accompanying the higher coals of the lower group.—To avoid a large number of lists, the plants from the horizons of the other coals, all of which fall within an interval of not over 150 feet in the lower group, will be combined in one list. These horizons are the Gas, Tunnel, and Peerless, which have been regarded by the state geologists [‡] as splits of the Lower Kittanning coal of the Allegheny valley; the Cedar grove, similarly correlated [§] with the middle Kittanning of Pennsylvania; and the Ansted-Cotton Hill coals. [||]

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[*] The differentiation of the Lycopodiales and Equisetales is easily recognizable, though in these groups of plants which possess less stratigraphic value it is less marked than in the ferns.

[†] *Archæopteris* cf. *stricta* Andr.,* *Eremopteris* sp.,* *Mariopteris pygmæa* D. W.,* *Mariopteris muricata* (Schloth.) Zeill.,* *Sphenopteris* cf. *linearis* Brongn., *Pecopteris plumosa* (*serrulata* Hartt),* *Neuropteris* n. sp.,* *Megalopteris* sp.,* *Calamites approximatus* Brongn., *Asterophyllites minutus* Andr.,* *Annularia cuspidata* Lx.,* *Calamostachys* sp., *Sphenophyllum saxifragæfolium* Sternb. [Lesq.],* *Lepidodendron* cf. *rushvillense* Andr.,* *Lepidostrobus variabilis* L. & H., *Lepidophyllum* sp., *Cardiocarpon cornutum* Dn. ?*

The species marked by the asterisk are closely allied to or identical with species of the Pottsville formation in the type region.

[‡] I. C. White: Bull. U. S. Geol. Survey, no. 65, p. 140.

[§] Op. cit., p. 167.

[||] The species in the list may be separated by referring to the abbreviations, each of which ends with the initials of the nearest coal. See p. 160.

Name.	Locality.
Eremopteris sp.†	P. P., C. G. P., Hand., Eb. C. G., R. C. G., Anst., C. H.
“ cf. *sauveuri* Stur.†	Eb. C. G.
Pseudopecopteris trifoliolata (Artis) Lx.	F. H. G., Tunn. T., P. P., Sl. P., B. D. P., Mon. P., Hand., B. C.
“ *obtusiloba* Sternb. var. *dilatata* Lx.	Eb. C. G., Bl. C. G., C. H.
Mariopteris muricata (Schloth.) Zeill.†	F. H. G., P. P., C. G. P., Sl. P., B. D. P., Mon. P., Hand., C. G. C., H. C. G., Eb. C. G., Bl. C. G., R. C. G., C. H.
Mariopteris cf. *jacquoti* (Zeill.)†	C. G. C.
“ *inflata* Newb.†	Diam. G., P. P.?, Anst.
“ *nervosa* (Brongn.) Zeill.*†	Diam. G., Eb. C. G., Anst.
“ *sphenopteroides* (Lx.) Zeill. n. var.	Eb. C. G.
“ *acuta* (Brongn.) Zeill.	C. G. P., Sl. P., B. D. P.
“ *andræana* (Roehl.) [Lesq.]	P. P., Eb. C. G., Bl. C. G., Anst.
Sphenopteris sp. cf. *hildreti* Lx.†	Eb. C. G., C. H.
“ *spinosa* Goepp?	C. G. P., Sl. P., B. C.
“ cf. *geniculata* Germ. and Kaulf.†	Eb. C. G., Bl. C. G.
“ cf. *schatzlarensis* Stur.	P. P., Mon. P.
“ cf. *canneltonensis* D. W.	Mon. P.
“ *delicatula* Sternb. [Lesq.]	Anst.
“ cf. *dubuissonis* Brongn.* [Lesq.]	F. H. G., P. P., Hand., B. C.
“ cf. *microcarpa* Lx.†	Tunn. T., P. P., Mon. P., Hand., B. C., C. G. C., Eb. C. G., Bl. C. G.
“ n. sp., cf. *crepini* Boul.	P. P., Anst.
Oligocarpia sp.†	Hand.
“ *alabamensis* Lx.?†	C. G. C.
Pecopteris plumosa Artis*†	Diam. G., Cr. G., M. C. G., Tunn. T., Anst.
“ n. sp., cf. *crenulata* Brongn.	Diam. G., Cr. G., M. C. G., Tunn. T., K. C. T., Anst., C. H.
“ cf. *aspera* Brongn.†	C. H.
Alethopteris serlii (Brongn.) Goepp.*	Diam. G., F. H. G., M. C. G., Tvnn. T., P. P., Sl. P., Mon. P., Hand., B. C., H. C. G., K. C. G., Eb. C. G., Bl. C. G., R. C. G., Anst.
“ *lonchitica* (Schloth.) Goepp.	C. G. P., C. G. C., Eb. C. G., Bl. C. G., Anst.
Neuropteris sp. cf. *gigantea* Sternb.†	Eb. C. G., Anst.

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* Identical with species in the Allegheny series.

† Identical with or modification of Upper Pottsville forms.

Name.	Locality.
Neuropteris flexuosa Sternb.‡	F. H. G., Diam. G., Cr. G., M. C. G., Tunn. T., P. P., C. G. P., Sl. P., B. D. P., Mon. P., Hand., B. C., C. G. C., Eb. C. G., Bl. C. G., Anst., C. H.
Neuropteris n. sp., no. 1	P. P.
“ n. sp., no. 2.†	Sl. P., Hand., Bl. C. G., Anst.
“ *cistii* Brongn.?	Eb. C. G., R. C. G.
Calamites ramosus Artis*	F. H. G., Eb. C. G., P. P., C. H.
“ *suckowii* Brongn.*	F. H. G., Eb. C. G., Bl. C. G., Anst.
“ *cistii* Brongn.*	Eb. C. G., Anst.
“ *approximatus* Brongn.*	C. H.
Calamitina sp.	M. C. G.
Calamodendron sp.	P. P.
Annularia ramosa Weiss.*	P. P., C. G. P., Sl. P., Hand., Eb. C. G., Anst., C. H.
“ *radiata* Brongn.*	P. P., C. G. P., Sl. P., Eb. C. G., Anst., C. H.
“ *acicularis* Dn.†	F. H. G., P. P., Eb. C. G.
Asterophyllites rigidus Sternb.*?	M. C. G., H. C. G., K. C. G., Eb. C. G.
“ cf. *minutus* Andr.†	C. G. P., Hand.
“ *lycopodioides* Zeill	Eb. C. G.
Calamostachys ramosa Weiss.*	P. P.
Sphenophyllum cuneifolium (Sternb.) Zeill.§ †	F. H. G., M. C. G., Tunn. T., P. P., C. G. P., Hand., C. G. C., H. C. G., Bl. C. G., R. C. G., Anst.
“ *furcatum* Lx. (form) †	Hand.
Lycopodites simplex Lx.? †	P. P., Eb. C. G., C. H.
Lepidodendron cf. *acuminatum* (Goepp.) Ung.†	Cr. G.
“ sp. cf. *brittsii* Lx.	F. H. G., Mon. P.
“ *veltheimii* Sternb.*†	M. C. G., Hand.
“ cf. *magnum* Wood.	Diam. G.
“ *clypeatum* Lx.*†	H. C. G.
“ *obovatum* Sternb.?	Diam. G., Tunn. T.
Lepidophloios sp. cf. *laricinus* Sternb.	M. C. G., Hand., Anst.

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* Identical with species in Allegheny series.

† Identical with or modification of Upper Pottsville form.

‡ The form from this group is specifically different from that reported from the Allegheny series under the same name.

§ Very narrow lax form figured by Lesquereux (Coal Flora, iii, pl. xciii, fig. 9) as *S. saxifragæfolium*.

Name.	Locality.
Bothrodendron n. sp., cf. *minutifolium* Boul.	F. H. G., M. C. G., P. P., C. G. P., Sl. P., Mon. P., Hand., B. C., C. G. C., K. C. G., Eb. C. G., Anst.
Lepidostrobus variabilis L. and H.	F. H. G., Diam. G., C. G. P., Mon. P., Hand., H. C. G., Anst., C. H.
" *ornatus* L. and H.?†	Tunn. T., K. C. T.
" sp. nov.?	K. C. G.
Lepidophyllum acuminatum Lx.*†	P. P.
" cf. *campbellianum* Lx.†	F. H. G., Diam. G., M. C. G., P. P., C. G. P., H. C. G., Anst.
" cf. *cultriforme* Lx.	Diam. G., M. C. G., K. C. T.
Lepidocystis obtusus Lx.†*	M. C. G., K. C. T.
Ulodendron majus L. and H.*	Eb. C. G., Anst.
Sigillaria cf. *reticulata* Lx.†	M. C. G.
" sp. cf. *ichtyolepis* Sternb.	Tunn. T.
Cordaites borassifolius (Sternb.) Ung.*	
Cardiocarpon minor Newb.†	Tunn. T.
Rhabdocarpos amygdalæformis Goepp. and Berg.*	Mon. P.
" *sulcatus* (L. and H.) Schimp.*	F. H. G., M. C. G., C. H.
" *multistriatus* (Presl) Lx.*	Anst., C. H.
Carpolithes fragarioides Newb.†	P. P., Anst.

RELATIVE AGES OF THE LOWER KANAWHA GROUP AND THE ALLEGHENY SERIES.

In the preceding list the asterisk (*) marks species which appear to be identical in form with material examined from the Allegheny series. It should, however, be noted that while these species, which constitute but a small percentage in the ferns, occur also in the Allegheny series, they do not include forms that are characteristic of that series. On the contrary, they comprise species which are either of wide range or which in most cases originate in the upper zone of the Pottsville formation. Referring again to the list, the species distinguished by the dagger (†) are either identical with or they are modifications of Upper Pottsville forms. The much greater percentage of species in the latter category falls far short of indicating the really very intimate connection of the floras of the lower group of the Kanawha series with those of the Pottsville formation, both in West Virginia and in the type district.

An examination of the combined floras from the lower half of the Kanawha series reveals at once the absence of both the characteristic and the omnipresent ferns of the Clarion and succeeding groups in northern Pennsylvania. The unfailing forms of the Neuropterids, the common and characteristic Annulariæ and Sphenophylla* which predominate at the base of the Allegheny series, as well as the entire group of higher Pecopterids, appear, so far as my inspection of more than 100 collections has extended, to be entirely absent from the lower half of the Kanawha series in southern West Virginia.

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* Identical with species in the Allegheny series.

† Identical with or modification of Upper Pottsville forms.

The plant life of the lower half of the Kanawha formation in southern West Virginia differs from that of even the lower portion of the Allegheny series of northern Pennsylvania, not only by the almost entirely different forms in the fern flora, but by the still more important relations of the flora as a whole. The fern (Annularian and Sphenophyllean) elements in the flora of the Allegheny series are essentially totally different from those in the Virginian Pottsville and offer a well marked contrast to the types found below the Homewood sandstone in the Allegheny valley or below the Buck Mountain conglomerate in the Pottsville district of the southern Anthracite field of Pennsylvania. The floras of the Allegheny series are by their composition bound to the higher coal measures. The plant associations in the Freeport group are, as may be noted in a scrutiny of the list (page 154), characterized by the development of the higher Pecopterid flora. The ferns of the Kittanning (page 151), like those of Mazon creek, Illinois, and Henry county, Missouri,† show the almost entire absence of Pottsville types, and while not so highly developed, especially in Pecopterids, they still compose a flora that is in close agreement with those of the base of the Upper Coal Measures or the Middle Coal Measures of the Old World. The flora of the Clarion group (see list, page 148) is characterized by a smaller proportion of the higher Pecopterid elements, and a consequent reduction in richness, rather than by any considerable representation of Pottsville ferns, Annulariæ or Sphenophylla. The flora of this the lowest group of the Allegheny series, with its abundant *Neuropteris ovata*, *Neuropteris scheuchzeri*, and "*Pecopteris villosa* (*?*)," as well as *Annularia stellata*, *Annularia sphenophylloides*, and *Sphenophyllum emarginatum*, is still bound to the higher floras, and is comparable to the Middle Coal Measures of Great Britain, or the upper zone of the Valenciennes, or the upper portion of the Westphalian series of the Old World.

In contrast to the composition and affinities of the floras of the Allegheny series, we find the floral associations in the lower half of the Kanawha series, including the lower group of coals, to be almost totally lacking in the characteristic elements of the Allegheny flora. The Lower Kanawha flora is distinctly largely of Pottsville derivation or affinity. Many of its elements are but slight modifications of types characteristic of the Pottsville of Virginia or of the southern Anthracite field, while the greater part of the remaining stratigraphic species either are closely allied to Pottsville plants or they are unfamiliar in our American Paleozoic floras. The comparative reference of a considerable number of the species in the latter category to the types described from the Valenciennes series or the Schatzlar series of the Old World is in itself a suggestion of the most intimate relations of the floras. It needs but a cursory examination of the magnificent and voluminous illustrations published by Zeiller * and Stur † to at once reveal the homotaxial significance of the floral composition of the Lower Kanawha flora and its exact reference to the Westphalian or Lower Coal Measures of the European basins. Thus not only does the Lower Kanawha flora appear by its composition and relations, when compared with the floral succession in the Pennsylvania section, to distinctly antedate the flora of the Clarion group in the lower portion of the Allegheny series, but the same relative positions for the two series are indicated also by a paleontological comparison of both with the Old World paleobotanical sections. In short, the plant life of the lower half of the Kanawha formation, with its new or unfamiliar types, forms an elaborate connecting link between the typical Pottsville or Millstone Grit floras and the Clarion flora in the Allegheny series.

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* The form of *Sphenophyllum cuneifolium* in the Allegheny series is broad leaved, often irregularly dissected in narrow tapering teeth, while that from the Lower Kanawha group and the Sewell formation has narrow, long, lax leaves, rarely cut in more than four relatively broad, obtusely pointed teeth.

†Age of the coals of Henry county, Missouri. Bull. Geol. Soc. Am., vol. 8, 1897, pp. 287–304. Flora of the Lower Coal Measures of Missouri. Mon. U. S. Geol. Surv., vol. xxxvii, 1899.

That the flora under discussion preceded the typical Allegheny floras, at least in the Virginia region, is further shown by the occurrence of the normal and characteristic plant associations of the Clarion and Kittanning groups at a higher stage in the Kanawha section.

FLORAS OF THE UPPER GROUP OF COALS IN THE KANAWHA FORMATION

Plant horizons.—As described by Campbell and Mendenhall, an interval of usually barren and arenaceous strata, which attains to a thickness of about 300 feet, lies between the lower and upper groups of coals in the Kanawha formation. Reference to their published sections shows these sandstones themselves to occur within the upper half of the entire thickness of the formation. The three exploited coals of the upper group are locally known as (1) the Kanawha Mining seam ; (2) the Coalburg seam, and (3) the Stockton seam. They have been respectively correlated and named by the geologists of West Virginia as identical with the Upper Kittanning, the Lower Freeport, and the Upper Freeport of the Allegheny valley.

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* Flore fossile de la bassin houiller de Valenciennes, 1886 and 1888.

† Die Carbon-Flora der Schatzlarer Schichten, 1885 and 1887.

Plants from the Kanawha Mining and Coalburg coals.—The roof shales of the Kanawha Mining and Coalburg coals do not appear generally to contain well preserved plants. From the rock dump at the Chesapeake mine, Lower creek, near Handley, specimens of *Lepidodendron modulatum* Lx. and a Sigillaria belonging to the *mamillaris* group have been obtained. *Lepidodendron modulatum* affords a slight indication of Allegheny age, although the Lycopodiales of the Carboniferous flora are of inferior stratigraphic value. The plant fragments from the horizon of the Coalburg seam at the Belmont mine, near Crown hill, and at Ronda, on Cabin creek, represent a very delicate, deeply dissected Sphenopteris, more lax than *Sphenopteris hildreti* Lx.; a Sphenopteris of the form identified in the unpublished work of Professor Lesquereux as *Sphenopteris delicatula* Bronn; two species of Neuropteris, one of which is probably identical with *Neuropteris flexuosa* Sternb., while the other belongs to the group represented by *Neuropteris gigantea* Sternb., *Calamites suckowii* Brongn., and *Lepidodendron* cf. *obovatum* Sternb. The plant representations from the levels of these two coals are too scanty to permit an attempt at correlation. They contain little that points distinctly to a position in the Allegheny series, while, on the other hand, the fern species differ in their facies from the forms in the Clarion or the higher groups in northwestern Pennsylvania.

Plants in the roof of the Stockton coal.—The Stockton coal, which has been identified with the Upper Freeport coal of the Allegheny valley by Doctor I. C. White, and has accordingly been made by him the topmost stratum of the Allegheny series in his correlations of the terranes along the Kanawha river, lies from 30 to 50 feet below the Black flint, beneath which the upper boundary of the Kanawha formation is drawn by Messrs Campbell and Mendenhall.

The plant collections from the roof of the Stockton coal at a number of localities † include the following species:

Name.	Locality.
Pseudopecopteris cf. *nummularia* (Gutb.) * Lx.	Bel., Buff., Sp.
Mariopteris muricata (Schloth.) Brongn.	Hur.
" *nervosa* (Brongn.) Zeill..‡	Bel.

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†Belmont mine, near Crown hill (Bel.); Buffalo Lick fork, five miles above Cannelton (Buff.); near the mouth of Hurricane creek (Hur.); Stanton mine on Kelleys creek (St.); Spanglers fork of Blue creek (Sp.), and from the drift back of the schoolhouse north of Pond gap (P. G.).

‡ Form characteristic of the Allegheny series.

Name.	Locality.
Sphenopteris karwinensis Stur	Buff., P. G.
“ cf. *trichomanoides* Brongn.*	Buff.
“ cf. *broadheadi* D. W.*	P. G.
“ *tenella* Brongn. [Lesq.]	Buff., P. G.
“ *mixta* Schimp.*	Bel., P. G.
“ cf. *crepini* Boul	Buff., St.
“ *ophioglossoides* (Lx.)?*	Buff.
“ *hymenophylloides* Lx.*	Hur., St., P. G.
Pecopteris villosa Brongn.?* [Lesq.]	P. G.
Alethopteris serlii (Brongn.) Goepp	Buff., Sp.
Neuropteris cf. *gigantea* Sternb	St.
“ *rarinervis* Bunby.*	Bel., Buff., Hur., St., P. G.
“ *ovata* Hoffm.*	P. G.
“ sp. cf. *carrii* Lx.*	Sp.
“ *scheuchzeri* Hoffm.*	Bel., Hur., St., Sp.
Calamites ramosus Artis	St.
Asterophyllites equisetiformis (Schloth.) Brongn.*	Bel.
Annularia ramosa Weiss	Bel., St.
“ *stellata* (Schloth.) Wood*	Bel., St., P. G.
“ *sphenophylloides* (Zenk.) Gutb.*	Buff., St., P. G.
Sphenophyllum cuneifolium (Sternb.) Zeill	Buff., St., Sp., P. G.
“ *lescurianum* D. W.*	Buff., P. G.
“ *emarginatum* Brongn.*	Sp.
Lycopodites meekii Lx.*	Hur., St.
Lepidodendron cf. *brittsii* Lx.*	Bel.
“ *lanceolatum* Lx.*	Hur., St.
“ *modulatum* Lx.*	P. G.
Bothrodendron cf. *minutifolium* Boul	St.
Lepidostrobus cf. *variabilis* L. and H.	Bel., St.
Lepidophyllum lanceolatum L. and H.?*	St.
Lepidocystis vesicularis Lx	Buff., St.
Sigillaria cf. *fissa* Lx.*	Hur.
Poacordaites sp	P. G.
*Cordaicarpon cinctum**	P. G.
“ *circularis* Lx.?*	St.
Palæoxyris appendiculata Lx.*	St.

THE STOCKTON COAL FLORA AN ALLEGHENY FLORA

It needs but a brief comparison of the foregoing list with the lists of Allegheny plants to show the large proportion of forms (marked with the asterisk) identical with those found in the Allegheny valley. Moreover, the forms so designated are in general typical of the Allegheny series, and, so far as I recollect, have not been found elsewhere than in that or the higher terranes. The Stockton flora is almost completely composed of species found in the Allegheny valley in Pennsylvania, at Mazon creek, Illinois, or in Henry county, Missouri. In short, we have here a normal association of the identical and characteristic forms of the Allegheny series—a typical Allegheny flora.

It is not within the scope of this paper to more precisely discuss the equivalence in the Pennsylvanian section of the several Kanawha terranes. It is, however, proper to add that the absence of the higher Pecopterids, the presence of certain phases of the species, certain older elements, as well as the proportion and range of the identical forms, bespeak for the Stockton flora a place probably not higher than the Clarion group in the Allegheny series. It seems very improbable that it can in any event be so high as the Upper Kittanning.

FLORAS SUCCEEDING THE KANAWHA FORMATION

PLANTS LESS THAN 200 FEET ABOVE THE "BLACK FLINT"

As bearing upon the question of the position of the Stockton flora in the Pennsylvania section, while further showing the occurrence of the typical Pennsylvania floras, it is of interest to glance at the floras succeeding the Stockton in the southern West Virginia section. I therefore append three lists of plants from higher horizons in the same section.

The first of these floras, from localities[*] which Mr Campbell informs me lie within 200 feet above the Black Flint is as follows:

Name.	Locality.
Pseudopecopteris obtusiloba (Sternb.) Lx	Wayne.
“ *squamosa* (Lx.),† large	Clen., Wayne.
Mariopteris sillimanni (Lx.)†	Gr., Wayne.
“ *nervosa* (Brongn.) Zeill	Wayne, Liz.
“ *newberryi* (Lx.)†	Clen.
Sphenopteris solida Lx.†	Wayne.
“ *chærophylloides* (Brongn.) Presl †	Clen.
“ *mixta* Schimp.†	Wayne, Liz.
“ *ophioglossoides* (Lx.)†	Clen., Cob., Wayne, Liz.
Pecopteris emarginata (Goepp.) Presl †	Cob., P. R.
“ *unita* Brongn.†	Clen., Wayne, Liz.
“ *solida* Lx.†	Clen.
“ *villosa* Brongn.? †	Gr., Clen., Cob., Wayne, Liz.
“ *vestita* Lx.†	Clen.
“ *oreopteridia* (Schloth.) Sternb.†	Gr.?
“ cf. *jenneyi* D. W.†	Wayne.
“ *miltoni* (Artis) ? †	P. R., Wayne.

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[*] The collections here roughly listed are Graham mine, Mason (Gr.); along the Elk river, one mile above Clendennin (Clen.); Cob mine, near Clendennin (Cob.); from an horizon about 200 feet above the Black Flint, one-half mile east of Pleasant Retreat (P. R.); Left fork of Mill creek, Wayne county (Wayne); south of summit on Belva and Lizemore road (Liz.); Gunter hollow, near Mason (G. H.).

† Forms apparently identical with those in the Allegheny series.

Name.	Locality.
Alethopteris serlii (Brongn.) Goepp	Wayne.
Neuropteris rarinervis Bunby.*	P. R., Liz.
“ *vermicularis* Lx.*	G. H.
Neuropteris fimbriata Lx.*	Clen., Wayne.
“ *ovata* Hoffm.*	Clen., P. R., Wayne.
“ *scheuchzeri* Hoffm.*	Gr., Clen., P. R., Wayne.
Odontopteris subcuneata Bunby.*	Gr.
“ *æqualis* Lx.*	Liz.*
Calamites cistii Brongn	Clen.
Annularia ramosa Weiss	Wayne.
“ *stellata* (Schloth.) Wood *	Gr., Cob., P. R., Wayne.
“ *sphenophylloides* (Zenk.) Gutb.*	Gr., Wayne.
Sphenophyllum emarginatum Brongn.*	Clen., Cob., Wayne, Liz.
“ *majus* Bronn *	Clen., Wayne.
Lycopodites pendulus Lx	Wayne.
Lepidophyllum brevifolium Lx	Clen.
“ *oblongifolium* Lx.*	Clen., Liz.
Lepidocystis vesicularis Lx	Wayne, Liz.
Sigillaria camptotænia Wood *	Clen.
“ *fissa* Lx.*	Wayne.
Cordaicarpon gutbieri Gein.*	Wayne.
Carpolithes ellipticus Sternb.*	Cob.

PLANTS 200-300 FEET ABOVE THE “BLACK FLINT”

A small collection of plants from the road north of Clay Courthouse is reported by Mr Campbell as probably between 200 and 300 feet above the Black Flint, although his stratigraphic fieldnotes are not yet compiled so as to more precisely fix the position of the horizon. Another lot of fossils, from an horizon probably no higher, is from Granny branch of Indian creek, near Mason. These small lots contain:

Name.	Locality.
Pseudopecopteris squamosa (Lx.)†	Gran.
Mariopteris sphenopteroides (Lx.) Zeill.†	Gran.
“ *sillimanni* (Lx.) †	Gran.
Sphenopteris pinnatifida Lx.? †	Clay.
“ cf. *stipulata* Gutb	Gran.
“ *sagittatus* (Lx.) †	Clay.
Pecopteris dentata Brongn.†	Clay.
“ *villosa* Brongn.? †	Gran., Clay.
“ *miltoni* Artis †	Clay.
Neuropteris rarinervis Bunby.†	Clay.
“ *ovata* Hoffm.†	Gran., Clay.
“ *fimbriata* Lx.†	Clay.
“ *scheuchzeri* Hoffm.†	Gran., Clay.

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* Forms apparently identical with those in the Allegheny series.

† Identical species in the Allegheny series.

Name.	Locality.
Linopteris obliqua (Bunby.) Pot.*	Clay.
Odontopteris wortheni Lx.*	Gran.
Annularia stellata (Schloth.) Wood*	Gran., Clay.
Sphenophyllum emarginatum Brongn.*	Gran., Clay.
Lepidodendron modulatum Lx.*	Gran.
Lepidophyllum jenneyi D. W.*	Gran.
“ *hastatum* Lx.*	Clay.
Sigillaria camptotænia Wood*	Clay.
Carpolithes ellipticus Sternb.*	Gran.

SPECIES 300–400 FEET ABOVE THE “BLACK FLINT”

Two other small collections from horizons said by Mr Campbell to be between 300 and 400 feet above the Black Flint were obtained near Lavalette (Lav.), on the Huntington pike, and Furnace Hollow † (Fur.), Wayne county. They include:

Name.	Locality.
Mariopteris nervosa (Brongn.) Zeill	Fur.
Pecopteris dentata Brongn	Fur.
“ *villosa* Brongn.?	Fur.
“ *oreopteridia* (Schloth.) Sternb	Fur., Lav.
“ *polymorpha* Brongn	Lav.
“ n. sp.?	Lav.
Alethopteris pennsylvanica Lx.?	Fur.
Callipteridium inæquale Lx	Fur.
Neuropteris rarinervis Bunb.?	Fur.
“ *scheuchzeri* Hoffm	Fur.
“ *agassizi* Lx.?	Fur.
Annularia sphenophylloides (Zenk.) Gutb. var. *intermedia* Lx	Fur., Lav.
Sphenophyllum emarginatum Brongn	Fur.
“ *majus* Bronn	Fur.
“ *thoni* Mahr.?	Av.
Lepidodendron modulatum Lx	Fur.
Lepidophloios sp.	Fur.
Lepidophyllum oblongifolium Lx	Fur.

ALLEGHENY FLORAS ABOVE THE “BLACK FLINT”

It needs but a glance at the first two of the three preceding lists to recognize the typical constitution of the Allegheny floras. While it is not my present purpose to attempt by analysis to arrive at an estimation of the approximate positions of these plant associations, I may here express the opinion that the collective flora enumerated in the first list shows so high a degree of identity and so similar a composition to the floras of the Kittanning group of Pennsylvania as to strongly argue for a reference of some portion at least of the beds within 200 feet above the Black Flint to the latter group. Likewise, for reasons which cannot here be discussed, I am inclined to the belief that the small flora from beds between 200 and 300 feet above the Black Flint may be from terranes not later than the Freeport group. The species in the third list, though few in number, do not appear to indicate a stage very far above the horizon of the Upper Freeport coal, the upper limit of the Allegheny series. The evidence on this point is, however, at present too insufficient to justify further consideration.

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* Identical species in the Allegheny series.

† Near the mouth of Labor creek.

Homotaxial Relations of the Kanawha and Allegheny Series

GENERAL CORRELATIONS INDICATED BY THE FOSSIL FLORAS

From the foregoing brief reviews of the floras of the Kanawha formation and the Allegheny series, it appears:

1. That the floras of the lower half of the Kanawha formation, including the lower group of coals, are either of Pottsville derivation or they are identical with or closely allied to species which are characteristic of the Lower Coal Measures of the Old World, but are hitherto unknown in our own American coalfields.* The floras in question exactly correspond to those of the Lower Coal Measures of Europe.

2. The Lower Kanawha floras are in strong contrast to and are easily distinguished from either the floras of the upper part of the Kanawha series itself or the lower portion of the Allegheny series, which carries a flora slightly younger than that of the Lower Coal Measures of Europe.

3. The floras of the entire lower half of the Kanawha formation are homotaxially if not actually older than the Clarion and Kittanning floras, which follow them several hundred feet higher in the same section.

4. In the Virginian region the characteristic plants, everywhere common in the Allegheny series, do not appear until we pass up into the upper half of the Kanawha formation, where they occur in identical forms and in an association constituting a flora typical of the lower portion of the Allegheny series.

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* The reader should again be reminded that many of the specific identifications recorded in the foregoing plant lists are either tentative or comparative, and are therefore subject to change in connection with their systematic description in the full report.

5. The flora of the Stockton coal in southern West Virginia is typical of the Allegheny series in Pennsylvania, its common species seeming to indicate a place in the Clarion or lowest group of that series, while a portion at least of the Kittanning flora, as well as the Freeport floras of northwestern Pennsylvania, appear to occur in nearly typical development and associations, as well as in regular order, above the Black Flint, which immediately succeeds the Kanawha formation.

6. While the evidence of the fossil floras distinctly shows the homotaxial representative of the Clarion group to be in the upper portion of the Kanawha group, the preliminary and incomplete inspection of the higher floras leads us to somewhat confidently expect that the equivalents of the upper portion of the Kittanning group, as well as the entire Freeport group, are to be found in the terranes above the Black Flint.

7. The application of the names of the Allegheny coals to the several individual coals of the Kanawha series is in direct contradiction to the testimony of the fossil plants, since, so far my observations have extended, the earliest of the characteristic Allegheny floras is not found far below the vicinity of the Stockton coal, hitherto supposed to be the equivalent of the Upper Freeport of Pennsylvania, while the entire lower group of Kanawha coals, hitherto supposed to include the Middle Kittanning, Lower Kittanning, and Clarion coals, etcetera, of Pennsylvania, are paleobotanically older than the lowest coal of the Allegheny series. According to the evidence of the fossil floras, the Black Flint is to be compared with the horizon of the ferriferous limestone rather than with the phases of the Mahoning sandstone.

As has already been stated, the paleontologic data as yet in hand from the Kanawha Mining and Coalburg seams are not sufficiently complete to definitely indicate the relations of these two coals, which have been regarded as Upper Kittanning and Lower Freeport respectively, to the Allegheny series. It should, however, be noted that the fossils from the roof of a coal on Kelleys creek, about 100 feet above the Cedar Grove seam, have the characters of the Lower Group floras without showing any of the distinctive paleontologic features of the Allegheny series. If we assume the Coalburg and Kanawha Mining seams also to be referable to the latter series, an assignment to any horizon above the Clarion group seems to be clearly unwarranted.

REASONS FOR ASSUMED CONTEMPORANEITY OF THE IDENTICAL FLORAS

The paleontologic conditions here shown to exist in the Allegheny and Kanawha series admit of two explanations: (*a*) either the terranes of the Allegheny series have no representatives or contemporaries in the Kanawha formation except in the upper, lesser, portion of the latter, the entire lower half of the formation being older, or (*b*) the Kanawha and Allegheny are essentially equivalent, the respective floras being homotaxial, not contemporaneous. The question is whether, if there be no unconformability at the base of the Allegheny series in the Pennsylvania sections, the upper beds of the Pottsville formation have changed their distinctive lithologic characters so that the lithologic boundary between the Allegheny series and the Pottsville formation diagonals in time in passing from the Allegheny valley to the Kanawha river, or whether the successive floras existed in Pennsylvania long before they reached southern West Virginia.

In support of the first hypothesis, we have (1) the existence, in the lower Kanawha group, of floras by composition and relations distinctly antecedent to those in the Allegheny series; and (2) the presence of the typical floras of the Allegheny series occurring in characteristic composition, and apparently in regular sequence, in higher beds, above the older floras, in the same section along the Kanawha river. In proof of the second hypothesis, there is the well founded presumption, based on stratigraphic demonstration in certain more northern portions of the great basin, that the several formations preserve their characters as well as continuity along the Appalachain trough; and (2) the testimony of several of the stratigraphic geologists, including one of the most distinguished authorities, who have studied the Virginian region, in favor of the persistent characters of the beds.

The supposition that the paleontologic differences between the two formations are due to diagonalling in time on the part of the floras involves the further supposition that a maximum thickness of over 600, perhaps over 900, feet of sediments, including several calcareous beds and at least four workable coals, were laid down in the Kanawha region while well defined and characteristic groups of plant species were migrating from Pennsylvania to southern West Virginia. This I believe to be absolutely untenable for the following reasons: (*a*) The migration, if occurred, was made along a continuous coast bordering the eastern margin of the Upper Carboniferous sea; (*b*) a presumably low coastal plain offered a direct and easy route; (*c*) the prevailing direction of the currents at the close of Pottsville time, as indicated by the bedding of the sandstones along portions of the trough, was from north to south, thus favoring a speedy journey; (*d*) the fruits of many of the types appear to have been so constructed as to withstand drifting for some time; (*e*) practically the entire plant association must have migrated en masse, so the flora as a whole appears in the Kanawha region in nearly its exact Pennsylvanian composition and facies; (*f*) under the above conditions it is unreasonable to suppose that a migration, assuming such a one to have occurred, of less than 300, probably less than 150, miles* would have required so long a period as that represented in the sedimentation of the lower half of the Kanawha formation.

The far greater migration of the interglacial flora in pursuit of the retreating ice must, as timed by the comparatively thin sediments formed under the most favorable conditions during the Pleistocene period, have required but a relatively short interval. Furthermore, if it be assumed that during earlier Kanawha time the marsh or peat bog which represented the depository of each of the Allegheny coals stretched practically continuously from the Allegheny Valley region to the Kanawha region, as is implied by the correlations and usage of the West Virginia geologists, we must believe that several floras would have been met by the traveler in passing from south to north across the great marsh or bog, a condition which would indicate a difference of climate in Carboniferous time far greater than that to be found under similar circumstances within the same latitude at the present day; or, if we suppose the coals to have been formed by flotation of the carbonaceous matter, a theory in many cases more satisfactory, it becomes probable that an intermingling of the species from different portions of the basin would have occurred in the quiet waters of plant deposition.

Since it is generally admitted that the Pottsville formation, which is said to be represented by but 160 feet† of sediments in the Broad Top coalfield of southern Pennsylvania, attains a thickness of over 2,000 feet in the southern Virginia region, it is not improper to assume, on the other hand, that in the great expansion of the formation the upper beds may have lost their distinctive massive conglomeratic character and merged horizontally into shales, sandstones, coals, etcetera.

That such a change occurred is indicated by the observed distribution of the Pottsville floras, the apparent overlap of the lowest Kanawha floras on the type paleontologic section of the Pottsville, and the notable difference between the typical Upper Pottsville flora of the type section and the lowest flora of the typical Allegheny series. This difference is so great as to suggest that the group of upper conglomerates forming a plexus with the "Buck Mountain conglomerate" in the Southern Anthracite field, or perhaps the Homewood sandstone in the Allegheny valley, may represent a much greater time interval than is inferred from their proportionate thickness.

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* The actual discrepancy between the geological correlations and the evidence of the fossil plants occurs within the geographic interval between the Potomac basin and the Kanawha river, a distance of less than 150 miles.

† Bull. U. S. Geol. Survey, no. 65, p. 185.

EVIDENCE OF THE FLORAS AS TO THE ISOSTATIC MOVEMENT IN THE SOUTHERN VIRGINIAN REGION

The paleontologic observations made by me in the field are too incomplete to warrant more than an outline of the development of the indicated dilations. An examination of the fossils from the Allegheny series, as the latter has been stratigraphically traced in the Potomac basin in northern West Virginia, shows but little, if any, change in the normal position of the floras as far south as Thomas, in Tucker county, where the series is said* to be 273 feet in thickness.

Any great diagonalling, therefore, whether of floras or lithologic boundaries, must have occurred south of this region, or within 125 miles of the Kanawha and along the shore of the basin. A hasty examination of the available material leads me to believe that a slight change in the lithology of the uppermost beds of the Pottsville occurred in the region of Pickens, while on the Holly river, within 50 miles of the Kanawha, the absence of the typical Allegheny flora for some distance above the lithologic Pottsville boundary is noticeable. The field and plant data at hand indicate that the dilation and transformation of the beds immediately below the base of the Allegheny series progress rapidly from Sutton to the mouth of Twenty Mile creek. This most important change becomes more and more marked in proceeding along the margin of the coalfield from Holly river to the mouth of Gauley river, though the lithologically new, intermediate, sub-Allegheny series (Kanawha in part) seems to expand somewhat farther to the southwest.

The development and expansion of the terranes forming the lower half of the Kanawha formation, as distinguished lithologically from the Pottsville, occur in the same direction and in the same region as the great expansion of the Pottsville formation. The latter formation, which is but little more than 400 feet in thickness at Piedmont, on the Potomac river, or 733 feet† on the Blackwater, in Tucker county, and which appears to be but about 500 feet in Webster county, rapidly thickens along the basin of the Gauley river to over 1,600 feet where it meets the Kanawha river. The evidence of the fossil plants shows that the isostatic movement in the southern Virginian region which rendered possible the deposition of about 2,400 feet of distinctly Pottsville sediments in that portion of the Appalachian trough continued under conditions but slightly different during early Kanawha time. The conditions of subsidence and detrital supply and distribution in this region appear to have been such that the greater part of the Kanawha series was laid down within the interval represented in part at least by the conglomerates and sandstones of the uppermost Pottsville in the Potomac and northeastern basins.*

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*Op. cit., p. 127.

†Bull. U. S. Geol. Survey, no. 65, p. 187.

The subsidence in the Virginian basin appears to have waned rapidly northeastward from the Kanawha river, since beyond Webster and Upshur counties, about 75 miles distant, the Pottsville assumes a somewhat regular though variable thickness, while the thickness of the Allegheny series at Moatsville, Barbour county, hardly 100 miles from the Kanawha river, is, as I am informed by Doctor White, but about 350 feet. The transition from the northern to the southern phases of the formations would seem to be most marked in Braxton and Webster counties. There are indications that from the highly arenaceous and very variable sections in the latter region the lithologic boundaries diagonal somewhat rapidly in passing southward under the conditions attending the southern Virginian isostatic movement.

If, as I believe, the respective Allegheny floras in the Potomac basin, the Allegheny valley, and the Kanawha sections are contemporaneous, the major portion of the sedimentation in the Kanawha valley, or over 2,200 feet, eastern outcrop measurement, antedates the deposition of the Brookville coal in northwestern Pennsylvania. Similarly, from such paleobotanic evidence as is now in hand, it appears that the upper boundary of the representatives of the Allegheny series lies some distance, probably over 200 feet, above the Black Flint; so that from the paleobotanic standpoint the Cannelton and Mahoning coals in the Charleston section† cannot safely be regarded as younger than the Freeport group of the Allegheny valley. If this be true, the Allegheny series will show no extraordinary expansion on the Kanawha river, while the Conemaugh series‡ will retain its full normal thickness as in northern West Virginia or in Pennsylvania.

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* The paleontologic evidence bearing on this subject will be presented when the Pottsville and Kanawha floras are fully elaborated.

† Op. cit., p. 85.

‡ XIV, Lower Barren Measures; Elk River series.

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ENRICHMENT OF MINERAL VEINS BY LATER METALLIC SULPHIDES*

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(Presented before the Society December 30, 1899)

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INTRODUCTION

In the early history of the development of many ore deposits, especially those of silver and of copper, masses of rich sulphide ore are encountered which lie below the limit of surface decomposition, and which are very often soon passed through in mining and found to give place more or less abruptly to comparatively poor and base sulphide ores. In other cases "bonanzas" are encountered, which in many instances consist of rich ores of a mineralogic character wholly unlike the main mass of the mineral deposit; or sometimes fissures in a low grade ore are filled by a rich ore. Such masses are believed to be generally of later origin than the original vein filling, and as they enrich the vein they are designated as sulphide enrichments.

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Scope of Paper

This paper is an attempt to explain the genesis of such bodies of sulphide ores as enrichments formed by the redeposition of material leached from the vein, generally by superficial waters, and to show the chemical and mineralogic changes involved in the processes and the physical conditions under which the ores have been deposited.

Not only is the process one that has played an active part in the later history of ore deposits, but a consideration of its effects leads to a review of the changes in the history of the vein, more especially in regions where marked changes of water level have resulted from physiographic revolutions. At an early date I hope to present a clear illustration of the importance of this change of level in the ore deposits of Butte, Montana, where for some time past a study of the copper veins has been made by Professor S. F. Emmons and myself for the United States Geological Survey.

In the present paper I attempt to prove—

1. That the leaching of a relatively lean primary ore, commonly by surface waters (but it may be by deep seated waters), will supply the material in solution for such enrichment.

2. That the unaltered sulphides, especially pyrite, will induce precipitation; that the material precipitated is crystalline; and that a number of mineral species are commonly formed, and are now forming, in veins by such reactions.

3. That such minerals deposited in quantity may form ore bodies of considerable size (bonanzas) or may be disseminated through the lean primary ore in strings and patches, thus enriching the ore body as a whole and even making a former low grade body of sufficient value to work.

Definition of Sulphide Enrichment

By secondary sulphide enrichment is meant the concentration of the metals into high grade sulphide ore bodies. It differs from what is often called secondary enrichment (enrichment in which the character of the ore is improved by the removal of its worthless constituents and the nonremoval of the valuable metals), and it should not be confused with that enrichment due to circulating surface waters which results in the formation of masses of oxide carbonate sulphates, chloride or bromide ores, which are enrichments whose origin is more clearly apparent and about which there is no doubt. The latter deposits belong to the zone of oxidation proper and are the commonly accepted products of superficial alterations of ore deposits. Their mineral character is in sharp contrast to that of the sulphides, sulpharsenites, and sulphantimonides which form the subject of this paper.

Zone of Oxidation

The upper parts of ore deposits are generally more or less changed by atmospheric agencies and rarely show the same mineralogic and physical features that prevail in the lower part of the deposit. If the original deposit holds much pyrite the outcrop is often a mass of impure limonite, the "iron hat" or "gossan" of the mines. Lower down the altered, iron-stained vein matter contains the carbonates, oxides, and other ores resulting from oxidation. This uppermost part of the vein, which is often the most remunerative to work, especially in gold veins, is here designated the zone of oxidation, as oxidation has been complete in it. This zone practically corresponds to that of superficial alteration of most writers, though, as will be shown, it is really only the upper part of the portion traversed by downward seeping surface waters.

Zone of Enrichment*

Beneath the zone of oxidation and between it and the unaltered primary vein matter lies the zone of enrichment. Its upper limit is usually very sharply defined, and may be told by contrast with the rusty color of the overlying deposit, though there is no definite plane, but usually an extremely irregular boundary. The lower limit of the zone of enrichment is also very irregular, though in some cases it is sharply defined. Generally, owing to a fracturing of the original vein matter, the secondary sulphides occur in cracks and crevices extending down into the primary ore, even as far as many hundred feet, especially along fault planes which have become channels for descending waters.

Zone of primary Sulphides

The lowest part of the vein, below the permanent ground water level, consists of the unaltered sulphides which compose the original ore of the vein. This part constitutes the zone of primary sulphide ore.

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*This term has been already used by Kemp in discussing the chalcocite bodies of the Butte (Montana) copper veins. See Ore Deposits of the United States, New York, 1896, p. 163.

It is, perhaps, unnecessary to add that while sulphide enrichment is believed to be a common phenomenon in veins, it is not an invariable accompaniment, but is very often wanting.

Enrichments described by previous Writers

The importance of this secondary sulphide enrichment seems to have escaped the attention of most geological writers, though such deposits are familiar to many practicing mining engineers. The most prominent of French writers on oré deposits, De Launay, has, it is true, recognized this phenomenon, describing it as part of the phenomena of superficial alteration of ore deposits in an essay entitled "Contribution à L'Étude des Gîtes Métallifères." The second part of his paper is devoted to the phenomena of superficial alteration and of the renewal of migration in the constitution of ore deposits.* The recognition of the "renewal of migration" is the essential element of secondary sulphide enrichment. De Launay regards many vein fillings as formed by the direct leaching of preexisting ore deposits through a concentration of material. In the latter part of his paper De Launay gives a summary of what is known regarding the derivation and deposition of the various metals, and brings out the main facts upon which he bases his views.

Other writers have alluded in a casual way to this feature of ore deposits, Posepny, for example, says:

> "The chemical effects proceeding from the present surface . . . involve not only the phenomena on the surface itself, but extend beneath it to ground water level and even below that level as far as the vadose circulation is traceable.† . . . The solutions formed by surface waters, like those of mine waters, mostly find their way to the point where the water level reaches the surface, yet as a part of the ground water penetrates to greater depths, such solutions may very likely produce in the deep region itself impregnations which must, however, differ in character from those produced by the deep circulation.‡ Meteoric waters carrying oxygen, some carbonic acid, and minute amounts of chlorides will first oxidize whatever is oxidizable, especially metallic sulphides. The ferric sulphate formed by the decomposition of the easily attacked FeS_2 will immediately attack the latter minerals of the series." §

Penrose refers very briefly to this feature and says: "Hence the richest bodies of ore in a deposit often occur between the overlying altered part and the underlying unaltered part." ||

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*Sur le rôle des phénomènes d'altération superficielle et de remise en mouvement dans la constitution de ces gisements. Ann. des Mines, xii, 1897, pp. 119–228.

†Genesis of ore deposits, pp. 135, 136.

‡Loc. cit., p. 136.

§Loc. cit., p. 137.

||The superficial alteration of ore deposits. Jour. of Geology, vol. ii, p. 294.

Emmons has ascribed the origin of the great bodies of rich copper sulphides at Butte, Montana, to secondary deposition and transportation, and gives a very clear outline of the possible changes. For copper ores, however, there seems to have been for many years a general belief in secondary deposition based upon the generally accepted explanation of the origin of the black copper (sulphide) ores of Ducktown, Tennessee, as derived from the material leached out of the part of the vein now forming the gossan.

Kemp also says that the upper 400 feet of the Butte veins is leached of copper, while below are found the bornite and chalcocite bodies of the zone of enrichment.

Upon reviewing the literature of ore deposits the writer has been impressed with the almost total lack of evidence to show that secondary minerals might be formed by such leaching or decomposition of vein matter. In many cases bodies of rich ore are mentioned and their structural features and occurrence described, but no evidence of secondary derivation is given.

Chemical Changes

LEACHING OF GOSSAN ZONE

The superficial alteration of ore deposits, by which the upper part of a mineral vein is altered and decomposed, has been discussed by many writers and has recently been fully treated by Penrose.* It is, however, necessary to consider briefly the reactions involved, since the origin of the secondary sulphides lying between the gossan and the unaltered, original vein matter is usually due to descending—that is, surface—waters. In general, it may be stated that in many instances the secondary ores are deposited above the level of deep seated water, the so-called " permanent water level," but in others the surface waters descend by water-courses and channels below the general level of the uprising deep waters, and all such waters eventually mingle with them.

Surface waters descending through the relatively porous and open textured gossan of a vein are normally oxidizing, and on passing downward usually attack the unaltered sulphides and deepen and extend the zone of the gossan. As the waters descend they are robbed of their oxygen by the sulphides which they decompose, and percolating further downward the waters which at first were strongly oxidizing in character are now charged with various salts and frequently with free sulphuric acid.†

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* Jour. of Geology, vol. for April–May, 1894, p. 288. See also Emmens in Engineering and Mining Journal, vol. 54, December 17, 1892, p. 582.

† As, for instance, mine waters run through precipitating tanks at Butte, the zinc-bearing waters of Missouri, etcetera. Am. Jour. Sci., vol. xliii, May, 1892, p. 418.

They are still descending waters of surface origin, but have lost all the characters commonly ascribed to surface waters. This change is, of course, due to the reactions involved in the changing of the vein minerals to gossan. The common metallic sulphides of veins are pyrite, pyrrhotite, chalcopyrite, tetrahedrite, enargite, bornite, galena (with which quartz is most commonly associated as a gangue mineral) and a little less commonly calcite and other carbonates, and barite, etcetera. The changes by which this mixture is converted into a mass of porous, more or less pure limonite are briefly as follows: The pyrite alters to a mixture of iron sulphates and sulphuric acid, which, reacting on more pyrite, eventually forms a mixture of hydrated oxides (limonite ores). The reactions commonly assumed are as follows:

1. $FeS_2 + O_3 + H_2O = FeS + H_2SO_4$.
2. $FeS + H_2SO_4 = FeSO_4 + H_2S$.
3. $FeS_2 + O_2 + 2H_2S = FeS + 2H_2O + 3S$.
4. $S + O_3 + H_2O = H_2SO_4$.
5. $2Fe_2SO_4 + O + H_2SO_4 = Fe_2\,(SO_4)_3 + H_2O$.
6. $FeS + Fe_2\,(SO_4)_3 = 3FeSO_4 + S$.

Pyrrhotite, if present, is attacked as in the second equation given. Chalcopyrite and bornite are commonly assumed to consist of Cu_2S and Fe_2S_3. The iron sulphide molecule is attacked and dissolved by the ferric sulphate present in the water, leaving Cu_2S as an amorphous, sooty material. It is well known that ferric sulphate will attack and decompose metallic sulphides. It has been shown[*] that the order of attack will be first chalcocite, then galena, then blende, the reactions being of the same character as those by which the iron sulphide is attacked. The Cu_2S left by the alteration of the chalcopyrite is in turn attacked by the ferric sulphate, forming cupric sulphate, ferrous sulphate, and sulphur. Lead, zinc, and other metallic sulphides are in their turn attacked by ferric sulphate, forming a sulphate of the metal, together with ferrous sulphate and sulphur, the latter, of course, oxidizing at once to SO_2 and sulphuric acid.

> "It is therefore evident that all the metallic sulphides will be dissolved away, and were it not for further oxidation of the iron, gangue alone would be left. The process has been stated to be $12FeSO_4 + 6O + H_2O = 4Fe_2\,(SO_4)_3 + 2Fe_2O_3,\ H_2O$; that is, as no further supply of free sulphuric acid (or sulphur) is available, the ferrous sulphate can not form ferric sulphate and is therefore precipitated as in the equation and partly as a basic sulphate, $6FeSo_4\,O_3\,3Fe_2O_3\,(SO_3)_2$ an insoluble yellow substance precipitated from ferric hydrate and found also in nature." [†]

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[*] Emmens: Chemistry of gossan. Engineering and Mining Journal, vol. 54, December 17, 1892.

[†] Loc. cit., p. 583.

In very many cases that have come under the writer's notice chalcopyrite and pyrite carrying copper are seen altering to a soft, black, sooty substance which soils the fingers and is pulverulent when dry. This proves to be cupric sulphide when tested in the laboratory, but it is not crystalline. Its formation is readily understood if we accept the explanation just given of the alteration of chalcopyrite. Chalcopyrite being Cu_2S, Fe_2S_3, the iron sulphide molecule yields more readily to attacking solutions of ferric sulphate (which by hydrolysis are acid) than the cupric sulphide, and the iron is removed and Cu_2S left as the amorphous powder seen. This is said to occur because copper has a "very much greater affinity for sulphur than iron."* After the greater part of the iron is gone, or rather converted to sulphate, the ferric sulphate solution attacks the Cu_2S, forming the amorphous powder seen, and removes it in turn, and it is carried a greater or less distance before it is redeposited. In the Gold Hill (Rowan county, North Carolina) specimens the copper sulphide has not been carried far, and in a large measure has by the gradual lowering of the limit of oxidation been converted to oxide and carbonate and native copper. Hand specimens collected by me show all the stages of this alteration.

As the sulphate of lead is virtually insoluble in water, it can only be carried downward to form transposed, redeposited sulphides by an intermediate change to the carbonate through carbonate of lime, namely, $PbSO_4 + CaCO_3 = PbCO_3 + CaSO_4$. This carbonate is soluble in waters charged with carbon dioxide, but is precipitated by carbonate of lime as lead carbonate. Galena is also dissolved by copper sulphate, as shown by experiments in which, after eleven months' immersion, the galena was etched, and lead sulphate and a subsulphate of copper was formed.† If the vein contains much pyrite, supplying an abundance of iron sulphate, the upper part of the vein will be leached of all its valuable metals, including gold and silver, as it is well known that ferric sulphate dissolves with great ease, not only the copper sulphides, but also the small content of precious metals of the ore, the reactions being similar to those just given.‡ If the amount of ferric sulphate present is relatively small, copper oxide and carbonates will be formed in the lower part of the gossan and in cracks and fissures in the underlying sulphide ores, be they original or secondary.

That the metals are leached out of the gossan and go into solution is well known at almost all copper mines. For other metals the evidence is also abundant. The composition of a surface water filling a mine shaft 130 feet deep, noted by Haworth,* the spring water of unquestioned superficial character from Missouri, analyzed by Hillebrand,† and a great many analyses of vadose waters, published by Emmons ‡ and various other writers, establish this fact beyond a doubt.

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*The series is Hg Ag Cu Sb Sn Pb Zn Ni Co Fe As Mn (E. & M. Jour., Oct. 25, 1890, p. 484). See F. Sandburger: Untersuchungen über Erzgänge, 1882, and Vogt: Zeitschrift für Praktische Geologie, vol. i, 1893, p. 262.

†Compte Rendu, vol. xx, 1845, pp. 1509–1536.

‡Vogt: Zeitschrift für Praktische Geologie, July, 1899.

If other proof were needed, the stalactites formed in mines afford convincing evidence of the solubility of metallic sulphides in deoxidized waters. Stalactites of blende and of galena are found in the mines of Missouri. The percolating waters of many copper mines deposit stalactites of hydrated iron oxide, and of copper and aluminous sulphates. Such deposits have been found in the Copper Queen mine near Bisbee, Arizona, and at Butte, Montana. Douglas describes a spring water which oozes from feldspathic rocks at the copper basin, Yavapai county, Arizona.§ On exposure to the air an insoluble mass separates out which has the composition given below:

Silica	7.17
Iron and alumina	16.21
Copper oxide	64.40
Sulphur trioxide	12.22

In time this sludge is converted into a mixture of carbonate of copper and alumina that binds together the gravel into a conglomerate.

Sulphide of zinc unquestionably formed by the action of cold sulphuretted water coming in contact with an aqueous solution of zinc sulphate has been found at Galena, Missouri. The deposit was amorphous, and an analysis by J. Dawson Hawkins showed the following composition: ||

Silica	1.49
Fe	1.79
Zn	64.17
Sulphur	32.86
" free	0.082
Total	100.392

DEPOSITION OF MATERIAL FROM SOLUTION IN THE ENRICHMENT ZONE

When the waters holding the metals in solution trickle down into cracks and crevices of the underlying pyritous ore the ferric sulphate is reduced to ferrous sulphate, and the gold, silver, and copper are precipitated.¶

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* Geology of lead and zinc district of Cherokee county, Kansas, 1884, p. 34.

† Am. Jour. Sci., vol. xlii, May, 1892, p. 418.

‡ Mines of Custer county, Colorado, Seventeenth Ann. Rep. U. S. Geol. Survey, 1896, p. 411 et seq.

§ Trans. Am. Inst. Mining Engineers, February, 1899, p. 25 of pamphlet edition.

|| Malvern W. Iles: Engineering and Mining Journal, vol. 49, March 5, 1899, p. 499.

¶ Vogt: Das Huelva Kiesfeld, Zeitschrift für Praktische Geologie, July, 1899, p. 250.

Though the reduction of copper sulphate to chalcocite does take place to a limited extent in the oxidized zone, where the glance is generally soon changed to oxide, the great bodies of glance and bornite found beneath the water level are probably not formed in this way; they result from reactions which do not involve the presence of free oxygen, but depend on a reduction of the copper sulphide by pyrite from the sulphate solution. The experiments of Brown show that both pyrite and marcasite are decomposed by copper sulphate, and copper sulphide is formed.* According to the modern theory of solutions, cupric sulphate in solution undergoes partial electrolytic dissociation, forming $Cu(OH)_2$ and H_2SO_4, the latter being ionized to $2\overset{+}{H}$ and $\overset{=}{SO_4}$, while part of the $CuSO_4$ is ionized to $\overset{+}{Cu}$ and $\overset{=}{SO_4}$. The writer has added H_2S to a solution of pure copper sulphate and obtained a precipitate of copper sulphide, and this is greatly increased in amount if some free H_2SO_4 be added. It has been asserted that pyrite when powdered and treated with very dilute sulphuric acid will give off sulphuretted hydrogen. Qualitative tests made for me by Dr H. N. Stokes in the Survey laboratory upon perfectly pure pyrite failed to confirm this statement. If, however, pyrrhotite is added, hydrogen sulphide is at once evolved. It was found, however, that the pyrite from the Butte quartz veins, carrying mere traces of copper, when powdered and treated with dilute sulphuric acid gave off sulphuretted hydrogen, and that the purest chalcopyrite of Ducktown, Tennessee, and cupriferous pyrite of Gold Hill, North Carolina, behaved in the same way. It is therefore certain that the pyrite of these deposits is capable of precipitating copper sulphide from down seeping waters holding copper sulphate and sulphuric acid. This reaction might be expressed as $4CuSO_4 + 3FeS_2 + 4H_2O = 2Cu_2S + 3FeSO_4 + 3H_2SO_4 + H_2S$, and for pyrrhotite, $2CuSO_4 + 2FeS = Cu_2S + 2FeSO_4 + S$, while for chalcopyrite $2CuSO_4 + Cu_2SFe_2S_3 + H_2SO_4 = 2Cu_2S + 3FeSO_4 + H_2S$. The hydrogen sulphide would, of course, at once attack any $Cu(OH)_2$ present in the water and form copper sulphide. In these reactions the influence of $FeSO_4$ has for simplicity been left out. The H_2S formed by the decomposition of the pyrite will attack the metallic sulphates present and form sulphides, as shown by Doelter.†

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*Proc. Amer. Philos. Soc., vol. xxxiii, May 18, 1894.

†This investigator has made sulphides by the method of Senarmont, with the difference that he made them at temperatures below 100 degrees, and the time was extended over several days or weeks. As a starting point he frequently used minerals which contained one constituent of the product which was to be prepared. Thus small cubes of galena were formed from cerussite which was treated several days in a closed glass tube at a temperature of 80 to 90 degrees. In the same manner crystals of pyrite were formed from siderite, magnetite, or hematite; from cuprite, chalcocite. From malachite crystals of covellite were formed. (Translated from Chemische Mineralogie, Reinhard Braun, Leipzig, 1896, p. 266.)

Doelter also states that by the reaction of sulphuretted hydrogen on a solution of silver chloride and antimoniate of potash in presence of carbonate of soda in closed tubes at 80 to 250 degrees, miargyrite (Ag_2S, Sb_2S_3), pyrargyrite ($3Ag_2S, Sb_2S_3$), and stephanite ($5Ag_2S, Sb_2S_3$) were formed.* Silver sulphide, which is soluble in pure water, would be reduced by H_2S, with precipitation of the sulphide, and the sulpharsenate and sulphantimonates of silver may be formed in a similar way. Zinc sulphate is reduced to blende in the same manner. Doelter says, in writing of the artificial production of these minerals, that dilute solutions are more favorable than concentrated.† Sulphate of zinc is at ordinary temperature almost as soluble as sulphate of copper, even in the presence of carbon dioxide.‡ Bischof states that sulphates are precipitated by H_2S, resulting in dark colored masses, but when precipitated from a dual solution to which H_2S has been added gradually there forms on the surface of the liquid a thin film with the metallic luster of galena. Putting this in a filter and washing, one finds after partially drying that there are small particles with metallic luster.§ Although the sulphides prepared by precipitation from solutions of metallic salts are mostly amorphous masses without luster, they may be obtained artificially with metallic luster by the slow action of H_2S upon very weak solutions, or precisely the conditions which prevail in nature.¶

Silver brought into solution by ferric sulphate acting on argentiferous galena, blende, or pyrite probably forms silver sulphate. If there is an excess of ferrous sulphate thus formed and, as no more easily attacked substance is available, the ferrous sulphate and the silver sulphate will then form native silver, viz: $Ag_2SO_4 + 2FeSO_4 = Ag_2 + Fe_2(SO_4)_3$, and hence in many cases whatever silver is found in the vein remains in the gossan and is not leached out and redeposited at lower levels. Where other conditions prevail redeposition occurs.

R. C. Hills has suggested that the silver and the gold carried downward by waters holding ferrous and ferric sulphates has been precipitated through the decomposition of the sulphates by feldspar.**

As noted by Vogt and other observers at Konigsberg, native silver is abundant, as an alteration product of silver glance, below the zone of oxidation. He suggests that where native silver occurs in minute cracks in the country rock at such depths it may result from the reducing action of ferrous silicates.* Spurr found native silver occurring in similar situations at Aspen, Colorado.

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* Braun's Chemische Mineralogie, p. 267.

† C. Doelter: Allgemeine Chemische Mineralogie, Leipzig, 1890, chap. iv, p. 105 et seq.

‡ De Launay: L'argent, p. 70.

§ Braun's Chemische Mineralogie, p. 260.

¶ Bishop: English Trans., vol. iii, p. 451.

** Proc. Colorado Scientific Society, vol. i, p. 32.

In the lead mines of Missouri, Jenney says that the lead and zinc brought into solution by oxidizing waters are reduced and precipitated as sulphides by organic matter in the presence of alkaline sulphates, $PbO\ CO_2 + CaO\ SO_3 + H_2S + 2C = PbS + CaO\ SO_3 + 2CO_2$† $+ H_2O$.

MINERAL ALTERATION

A study has been made both in the field and office of the changes which take place in the alteration of the primary sulphides and of the paragenesis and the association of the redeposited (secondary) sulphides. The data are more abundant for copper than for the other metals because the facilities have been more abundant for the observations of such deposits, and many notes have been gathered in brief trips to Southern copper mines during the past four months. Dana says chalcopyrite alters to bornite, and bornite to chalcocite. I have observed the following alterations: Chalcopyrite to chalcocite, this to cuprite, this to malachite, and the latter to chrysocolla; also malachite to tenorite, and cuprite to native copper. Bornite is seen altering to chalcocite and hematite. The oxide and carbonate are, of course, formed only by superficial alteration, but native copper, like native silver, is found in places where its formation must be ascribed to the deep-seated reactions, not to oxidizing waters.

The black copper of Ducktown and Ore Knob obtained from the National Museum collection, as well as that collected by the writer at the mines, is proven by chemical tests made in the United States Geological Survey laboratory to be entirely chalcocite.

The fact that copper glance may be of secondary origin is not generally recognized, and has been denied by some geologists. Of this an examination of the specimens leaves no doubt whatever. Not only is the cupric sulphide formed by the alteration of chalcopyrite and bornite through the agency of descending surface waters, but the material is actually taken into solution and transported and redeposited as crystalline glance. In literature the first mention of crystalline material thus formed is in an account of the Ducktown material by Sterry Hunt, who states that crystals of glance were seen by August Raht in druses in the ore. In this ore, however, I myself have been unable to find any crystallized material, even after a very careful search on the ground.

The unequaled chalcocite crystals of the Bristol, Connecticut, copper mine occur in the oxidized zone,* and copper glance pseudomorphous after chalcopyrite in the quartz veins near Georgieff, in the Altai mountains, is described as occurring with hematite, chrysocolla, and malachite; also derived from copper pyrite.†

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* Jour. Praktische Geologie, April, 1899, p. 250.

† W. P. Jenney, in Trans. Am. Inst. Mining Engineers, 1893, p. 202.

Emmons and Tower have stated ‡ that chalcocite "occurs filling fractures in pyrite and chalcopyrite, and from its relation with these minerals and bornite it is certain that it is derived from the two latter minerals by decomposition, and is therefore later than these minerals." Bornite is also mentioned by the same writers as an alteration product of chalcopyrite.

Kemp has called attention § to the "general experience that the carbonates form most readily when the original sulphides are in limestone, whereas when granite or some similar crystalline rock constitutes the walls chalcocite or bornite results."

With these exceptions, I have not found in the abundant literature of mineral alteration and mineral synthesis any reference to the formation of crystalline glance by secondary alteration. I have therefore been somewhat surprised to find abundant evidence of it in copper ores, not only at Butte, but elsewhere in Montana, and also in the ores of North Carolina and Virginia. The glance so found is in all conditions: amorphous, massive without crystalline texture, massively crystalline, and in crystals.

Native copper, though commonly considered as a product of oxidizing waters only, also occurs, as already noted, under conditions which show that it has been produced far below the zone of oxidation and where no oxygen has been present. Thus Douglas has described || native copper as occurring in the Copper Queen mine, "not at the surface, where oxidizing agencies have been most active, but in the deepest layers of the large ore bodies, where apparently some reducing agent has been more actively at work than elsewhere and where the ore is farthest removed from atmospheric disturbance." In my own examinations I find that the native metal frequently occurs under similar conditions at many localities. It is not necessary, however, to suppose any new conditions, and the deposit is easily understood if, as is commonly the case, ordinary limestone be present. The carbonate of lime will reduce the copper sulphate to cuprous oxide, and this with either sulphuric acid or ferrous sulphate will form native copper, as shown by the following equations:

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* Silliman and Whitney, Am. Jour. Sci., 2d ser., vol. xx, p. 361.

† Jeremeef: Bull. Academy of Sciences, St. Petersburg, 1897, v. 6, p. 37; quoted in Zeitschrift Kryst. Mineralogie, 1899, v. 31, p. 508.

‡ Under "Paragenesis," in Butte Special Folio, folio 39, U. S. Geological Survey.

§ Ore Deposits of the United States, 2d ed., New York, 1896, p. 164.

|| Trans. Am. Inst. Mining Engineers, February, 1899.

$2CuSO_4 + 2CaCO_3 = 2CuO + 2CaSO_4 + 2CO_2$. The CuO is reduced to Cu_2O by organic matter in the limestone.

$Cu_2O + H_2SO_4 = Cu + CuSO_4 + H_2O$ or else $3Cu_2O + 3FeSO_4 = 6Cu + Fe_2O_3 + Fe_2(SO_4)_3$.

Specimens collected from the Union Copper company's mine at Gold Hill, North Carolina, are especially interesting. The primary ore is a rather fine grained gray quartz carrying small bunches, strings, and shreds of chalcopyrite.

The ore body is fractured by vertical planes down which the surface waters percolate and alter the vein, forming the well defined zone of oxidized ores and penetrating to a greater or less depth along the vertical cracks. As already noted in the preceding pages, the yellow stained oxidized ore passes into an ore in which the quartz is no longer translucent and solid but is opaque, white, and more or less saccharoid, and often porous, while the fragments of included schist have been changed by the acid waters to a white, clayey material. Specimens of this ore collected by me show the lower tip of a vertical "pipe" of oxidized ore surrounded by the altered but not yet oxidized ore. In the latter mineral black, sooty masses are seen whose form and distribution accord exactly with those of the chalcopyrite in the unaltered primary ore. The yellow stained oxidized ore differs in showing about its borders a band of massive crystalline glance often mixed with cuprite, the oxide predominating toward the very sharp line marking the limit of the yellow iron stained ore. The specimen shows that there has been a transposition of material and a redeposition of the copper as glance. This border or halo of enrichment is very common in the ore from this mine. In the more perfectly oxidized and iron stained ore the cuprite is changed to malachite, and the latter sometimes to chrysocolla. In other specimens from Gold Hill the altered white quartz carries copper glance, beautiful crystalline cuprite, and native copper. The glance occurs not only scattered through the ore but in little clusters of crystals through the clay and rotten quartz. Other specimens show massive crystalline glance a quarter of an inch thick coating the specimen, the surface of the glance coated with a very thin or felty covering of native copper.

In the main body of the vein there are also bunches several feet in diameter of massive, coarsely crystalline quartz. In this material the chalcopyrite is in masses an inch or more across. Where this ore has been altered the chalcopyrite has been changed directly to massive glance showing a crystalline texture, and the quartz about it is more or less iron stained and the glance surrounded by a film of red oxide of copper changing to fibrous malachite along cracks in the quartz.

In ores from Copperopolis, Meagher county, Montana, glance also occurs secondary after cupriferous pyrite, as shown by several specimens. The ores of the copper-bearing diabase dikes of the "Blackfoot ceded strip" in northern Montana also show this same alteration, with specular iron ore accompanying the glance.

Bornite altering to glance is a common feature of the ores of the Virgilina field in Virginia and North Carolina. Specimens from the Blue Wing mine show bornite cracked by minute fissures, along which alteration has taken place and left rounded cores of bornite surrounded by a shell of dull, conchoidally fracturing glance with iron oxide outside of this. The specimens taken below the level of permanent water show the bornite altered to chalcocite and the iron concentrated in nests of laminated specular iron ore.

The evidence showing the secondary nature of these copper minerals has been summarized from a large mass of material, for while many writers have assumed the secondary character of ore deposits formed of these minerals, no evidence has been given on which to base a judgment, and the facts have lately assumed a great economic importance in the legal fight now being made for the possession of several of the great copper veins at Butte, Montana.

The evidence of a secondary origin of other metallic sulphides is less abundant, but quite sufficient to be convincing. The first writer to describe the general occurrence of such minerals appears to be Walter P. Jenney, who notes their appearance in the lead and zinc deposits of the Mississippi valley.* He ascribes the formation of secondary sulphides of lead and zinc to the descending oxidized solutions which leach the upper parts of the original ore body. He says:

> "The minerals of secondary deposition are sulphides—pyrite and marcasite derived from the iron of the wall rocks; blende, galena, chalcopyrite, and greenockite produced by alteration from the primary ores in the zone of oxidation in the upper portions of the ore bodies and reformed as sulphides by the reducing action of organic matter in the deeper levels. In addition to these sulphides, sulphates, carbonates, silicates, and phosphates also occur, the most abundant being now anglesite from the alteration of galena. Barite occurs locally, probably derived from a gangue of the ore. Soluble sulphates of zinc, iron, and other metals are also found in the drip of the mines."

In discussing the order of deposition of the minerals he states that minerals of secondary deposition vary in their paragenesis, and the same mineral may occur more than once in the series. Though conforming to no absolute order, the prevailing sequence is as follows:

1. Crystallized white and rose-colored dolomite lining cavities in the ore body and filling interstices in the breccia.

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* Trans. Am. Inst. Mining Engineers, August, 1893, p. 29.

2. Crystallized blende, usually of garnet or ruby red color, often in small, brilliant, translucent crystals; crystallized galena.
3. Crystallized pyrite, marcasite, chalcopyrite, calcite, barite, and amorphous tallow clay.
4. Anglesite, cerussite, calamine, smithsonite, and greenockite resulting from the alteration of the ores.

It may be noted that the primary ores are composed almost wholly of simple sulphides of zinc and lead and of the gangue minerals dolomite and cherokite (crystalline silica with spots of bitumen). Calcite appears to be in all cases of secondary and late formation. Pyrite, marcasite, and barite are probably of both primary and secondary deposition, but are of subordinate importance.

In personal conversation upon the subject Mr Jenney tells me that the tests made for him of these redeposited sulphides show that the secondary minerals are always much purer than the primary ones; thus the blende, which is always colored by impurities in the primary ore, is almost pure and translucent in the redeposited form. The galena also is much purer in the secondary form.

In the paper quoted he says:*

"The perfect faces and sharp edges of crystals of blende and galena found lining the water channels in the lower parts of the ore body show that below the zone of oxidation no solution or decomposition of the metallic sulphides takes place. Even where the lead and zinc become oxidized and pass into solution in the circulating waters, contact with the organic matter contained in the rocks in the presence of alkaline sulphates, which occur in all mineral waters, immediately reduces and precipitates the metals as sulphides.

$$PbO, CO_2 + CaO, SO_3 + H_2O + 2C = PbS + CaO, CO_2 + 2CO_2 + H_2O.$$

"It is this protective action of the organic matter disseminated through the strata that has limited the zone of oxidation to so shallow a depth in the mining regions, for until all the carbon contained in the rocks is first consumed by oxidation, no decomposition of the minerals can occur or any segregation of minerals take place."

In the discussion of this paper, further notes are also given upon this process: †

"The only deposition now taking place is that resulting from oxidation of the previously existing ores and their reformation due to the secondary action of oxidizing surface waters precolating downward through the upper portion of the ore bodies. Stalactites of blende, galena, and marcasite, not infrequently of calamine, smithsonite, and cerussite, occur in the vugs and open channels in the ore bodies, but they all appear in all observed instances to have been formed by the secondary action of surface waters in the primary ore."

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* Trans. Am. Inst. Mining Engineers, 1893, p. 222.
† Ibid., p. 646.

In a memoir on the silver deposits of Neihart, Montana, I have described* the paragenesis of the ore and gangue minerals. From a careful study of the order of superposition of the minerals in distinct crusts, and in crystals upon earlier minerals, supplemented by that of thin-sections of the ores, it was found that galena, pyrite, and blende, which form the primary ore minerals, are decomposed, and that the silver is concentrated, together with arsenic and antimony, as polybasite and dark, ruby silver, and more rarely pure, transparent blende, pure galena, and pyrite are deposited as secondary minerals. The thin-sections show galena altering to spongy polybasite. Both polybasite and pyrargyrite occur on all other minerals as crystalline aggregates and crusts and are not in any case coated or dotted by other minerals. Some of the material shows that the deposition of these silver minerals is still going on in water holes below the normal water level at the Florence mine at Neihart. As described later, the occurrence of the minerals also affords good proof of their secondary character.

SUMMARY OF CHEMICAL AND MINERALOGIC EVIDENCE

The evidence afforded by a study of the original unaltered ore and of ore in various stages of alteration, together with that of the superficial waters draining masses of such ore, show that the original ore is leached by surface waters which take into solution the various metals, and, trickling downward, meet with and are decomposed by the sulphides of iron present in the unaltered ore below and deposit new sulphides of the metals. The copper, silver, and gold contents of the original ore are thus concentrated, usually with antimony and arsenic.

The mineralogic evidence shows that the chemical precipitates formed by the foregoing reactions are true minerals, and the study of hand specimens and of microscopic slides confirm the chemical changes outlined.

Mode of Occurrence of Deposits of Secondary Sulphide Ores

METHOD ADOPTED OF PRESENTING THE SUBJECT

In the following pages the occurrence of masses of exceptionally rich sulphide ores, such as copper glance, polybasite, ruby silver, etcetera, will be noted, and it will be shown that these facts prove the secondary nature of the ore. The genetic association of ores of this character with direct superficial alteration or secondary post-vein fractures will be indicated. The geologic evidence comprises the facts showing the position of the ores of the vein, their relation to structural or physical features, and the alteration of the ore bodies as masses in contradistinction to purely mineral alteration.

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*Geology of the Little Belt mountains, Montana, with notes on the Neihart, Barker, Yogo, and other mining districts of the region, Twentieth Ann. Rept. U. S. Geological Survey, 1899–1900, pp. 257–572.

For convenience of presentation the different ores have been grouped according to the predominance of their principal ore. This treatment necessarily involves a slight repetition, since silver often occurs with copper and lead with zinc.

COPPER

For many years past there appears to have existed among mining engineers and a few geologists a tacit and sometimes an openly expressed belief in the secondary derivation of many deposits of copper glance. This statement is based on a review of the published accounts of a number of copper deposits in which such an origin has been either implied or stated, though, as a rule, no evidence has been presented.* This belief, if it may be so called, has undoubtedly had its origin in the descriptions of the Ducktown, Tennessee, deposits, which are described in all the text-books on ore deposits. The mass of rich "black copper" ore lying between the limonite gossan and the unaltered pyrrhotite has been stated to be of secondary origin ever since 1856, when Whitney published his now classic work on "The Metallic Wealth of the United States." In accounts of these deposits by Sterry Hunt, Hermann Credner, Carl Henrich, and lately by Professor Kemp the secondary nature of these ores has not been questioned, and the commonly accepted theory of their origin has been the leaching of the former lean sulphide ores, now altered to gossan, and the redeposition of the copper to form the rich black copper ore. Recent studies of the copper deposits of the West have made it desirable to review the evidence on which this theory rests, and to ascertain if bodies of crystalline sulphides have been formed by such action I made a visit to this locality in December, 1899. As is well known, the conditions prevailing at Ducktown are peculiarly favorable for a leaching of the gossan zone. Rainfall is frequent and heavy, and an altitude of 1,700 feet above sea-level favors rapid and considerable changes in temperatures. Moreover, the region has not been glaciated, and the gossan zone has presumably been forming since the elevation of the Tertiary peneplain, to which the district belongs. The following extracts from the more important papers describing this locality will, it is believed, serve better than an account by me to show the occurrence and nature of the secondary ore.

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* See Kemp: Ore deposits of the United States, 2d ed., New York, 1896, p. 164.

Sterry Hunt wrote:*

> "The curious phenomenon of the occurrence of the black ores in these deposits between the gossan above and the unchanged pyritous ores beneath has often been described, and there seems no reason to question the received explanation that they owe their origin to the reduction, in some imperfectly explained way, of the sulphates formerly generated by oxidation in the upper portion of the lodes, which, as is well known, is changed into a porous mass of hydrous peroxide of iron holding more or less oxide and green carbonate of copper in its lower portions. Pyrrhotine is not without action on copper solutions, and its agency has been, with great probability, suggested by Professor Henry Wurtz as accounting for the precipitation of copper sulphide."

Secondary ores are described as consisting chiefly of sulphides, sometimes with an excess of iron, but more commonly with a large percentage of copper oxide. They are said to approach copper glance in composition, and it is said that crystals of glance have been observed by Mr August Raht in this ore, which at times approaches bornite and chalcopyrite in composition, and held in it grains of copper or crystals of red oxide.

> "It is commonly impregnated with copper sulphate, the drainage waters from which contain large quantities of this salt. As high as 5,000 pounds a month of cement copper have been obtained from these waters, in which the percentage of copper is about .001."

Henrich, in a paper on the Ducktown ore deposits,† says:

> "The black copper found below the gossan had a very little black copper ore or tenorite (CuO) in its composition. Most of the copper in it probably occurs as copper glance, giving to it the black color. Native copper and cuprite are occasionally present; malachite and silicates were found usually near the edges of the black copper ore bodies, and in seams and stringers in the lower part of the gossan. The walls alongside of the black copper zone were penetrated by seams and fissures extending 5 to 12 feet from the ore body and carrying green carbonates."

The following analysis made by Doctor A. Trippel is quoted by several authors in their descriptions of the Ducktown deposits:

CuO	5.76	3.80
Fe_2O_3	1.50	.63
S	18.75	25.40
Cu	71.91	41.01
Fe	.93	26.56
Sol. sulph	.72	1.78
	99.56	99.17

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* Trans. Am. Inst. Mining Engineers, vol. ii, 1874, p. 127.

† Ibid., March, 1895, p. 37.

I examined the old black copper workings at Ducktown and found that the layer of this ore conformed in a general way to the surface contour of the ground or more nearly to the surface of the underground waters. The accumulation of the ore in a well defined band or layer is believed to be due to the massive nature of the original ore, which is unusually free from vertical fissuring such as would afford access for waters to seep downward, while it does show flat or gently inclined fracture planes. The occurrence of the black ore, its impregnation with copper sulphate, the fact that it is generally moist with strongly acid water, all show that the process is still going on, and indeed, in small clefts in the upper surface of the pyrrhotite ore, what appeared to be recently deposited amorphous black copper ore was found. No crystalline ore was found in place, nor has any been seen in specimens of the ore in various collections. The deposit appears to be wholly a loose textured sintery mass of amorphous copper sulphide, often containing a residual skeleton of pyrrhotite. It is not, however, tenorite (CuO), nor has any tenorite been found in numerous samples from the Ducktown region tested by or for me.

The Stone Hill (Alabama), Ore Knob (North Carolina), and Hillsville (Carroll county, Virginia) copper mines, all of which closely resemble the Ducktown deposits in occurrence and character of ore,[*] also showed the same enrichment—a layer of "iron black friable, drusy, crystalline sulphuret ore inclosing grains of quartz, garnet, magnetite, and a black non-magnetic mineral. This ore carried 36 per cent of copper and had the mineralogical character of purple and vitreous ores."[†]

In Arizona oxidized ores of copper are described as passing in depth to chalcocite, and this into chalcopyrite below, at the Coronado vein,[‡] and in minor deposits near Bisbee.[§]

The first statement that secondary enrichments of copper veins were of general occurrence, and that the ores consist of crystalline glance and bornite, appears in a paper by De Launay.[||] He says chalcopyrite and cupriferous pyrite alter to bornite, chalcocite, cuprite, and gray copper, which form deposits that do not extend far in depth. The deposits of Monte Catini, in Tuscany, those of Rio Tinto and San Domingo, in Spain, and Butte, Montana, are cited as examples. The secondary nature of the last mentioned deposits is also maintained by Emmons in a report upon the ore deposits of that district.* He has suggested that the secondary deposition or transposition of the copper minerals at the Butte (Montana) mines may have been produced by waters descending from the surface. He says further:

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[*] Sterry Hunt: Trans. Am. Inst. Mining Engineers, vol. ii, 1874, p. 123; E. E. Olcott, in Trans. Am. Inst. Mining Engineers, vol. iii, p. 391; R. P. Rothwell, in Engineering and Mining Journal.

[†] Hunt: Trans. Am. Inst. Mining Engineers, 1874, p. 123.

[‡] A. F. Wendt: Trans. Am. Inst. Mining Engineers, vol. xv, p. 52.

[§] James Douglas: Copper resources of the United States. Trans. Am. Inst. Mining Engineers, September, 1891.

[||] Annales des Mines, vol. xii., 1897, pp. 191–195.

> "Secondary deposition, or transposition of already deposited minerals, has played an unusually important role. In the case of the copper veins it has not been confined to the oxidizing action of surface waters, which has resulted in an impoverishment of the ore bodies, but below the zone of oxidation it has resulted in the formation of the richer copper minerals, bornite, chalcocite, and covellite, in part at least, by the breaking up of original chalcopyrite. Unusual enrichment of the middle depths of the lodes has thus been caused. Whether the two processes of impoverishment and enrichment have been differing phases of the action of descending waters, or whether the latter may have been a later result of the rhyolite intrusion, has not yet been definitely decided. It is, however, fairly well determined that the enrichment of the copper deposits is so closely associated with the secondary faulting that it may be considered to be a genetic result of it.
>
> "In the silver veins surface oxidation has resulted in general in the enrichment of the ore bodies. No certain evidence of secondary enrichment in the sulphide zone of these ore bodies was obtained."

A very important contribution upon this subject has recently appeared, entitled "A Description of the Pyrite Deposits of the Huelva Region in southern Spain and the adjoining Portions of Portugal," in which Dr J. H. L. Vogt† says that the amount of copper in the pyrite of these ore bodies becomes in a general way less and less with increasing depth at the San Domingo mine. The ore which at the surface has 4 or 5 per cent of copper contains at a depth of 80 meters but 2 per cent. At 100 meters the copper contents has fallen to 1½ and 1¾ per cent, while at 130 meters in depth the ore holds only about 1¼ per cent. In the ores of the Dionisio mine the percentage, which is 4 per cent in the upper levels, has fallen to 2 per cent at 200 meters and to 2½ per cent at 350 meters. It is to be understood, he says, that the copper contents in different parts of the respective levels will vary somewhat, though the average contents always grow less in depth.

This impoverishment in depth has also been discussed by Klockmann.‡ He coincides with the view held by all the Spanish geologists, and says this constant decrease in depth of the copper contents is due to the fact that the original copper contents of the pyrite of the uppermost part of the vein went into solution through weathering, and that the copper-bearing solution then seeped down along cracks and fissures into the deeper lying pyrites. It there formed a new generation of minerals rich in copper; in fact that they do often find copper glance, bornite, and chalcopyrite, together with galena, zinc blende, tetrahedrite, etcetera, usually accompanied by some quartz, in the cracks and fissures in the pyrite, and these minerals are, without doubt, of younger, secondary formation. These secondary ores sometimes fill the cracks so large that they can be separately mined, and the mining done by the Romans was chiefly confined to these rich streaks within the poorer mass of pyrite. More commonly, however, the rich ores occur in quite small fissures which form a branching network in the main body of pyrite. That the copper contents of these secondary minerals has been derived from the weathered ore near the surface is shown quite clearly by the fact that these little veins are most common in the zone immediately under the gossan. They usually extend to some 100 meters or more in depth, while below this the pyrite is firm, little cracked, and comparatively poor in copper. In discussing these observations Professor Vogt says:

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* Butte Special Folio, folio 39, U. S. Geological Survey, 1898.

† Zeitschrift für Praktische Geologie, July, 1899.

‡ Ibid., 1895, p. 35.

> "The enrichment described by Klockmann of the copper contents of the upper part of the ore bodies undoubtedly plays a very important role. From my own examination of the different mines I have obtained, however, the impression that this process alone was not sufficient to account for the phenomena described, and that the decreasing copper contents in depth is in part of a primary nature."

For the sake of analogy he also mentions the fact that the copper contents of the ore body of the Vigsnas mine in Norway, which is now known to have a depth of 735 meters, becomes less in depth, and that this is also the case at Fahlun, where the pyrite body has been worked to a depth of 350 meters.

At Gold Hill, North Carolina, the workings of the Union Copper company show very fine examples of secondary sulphide enrichment, but there is no well defined zone or continuous mass, as the veins are fractured by vertical fissures. The unaltered ore is chalcopyrite, which occurs in quartz veins traversing schists, following the foliation in part. The ore occurs only in the quartz, which forms lenticular masses, as is commonly the case in schistose rocks. The veins have been worked during the 40 or 50 years past, the deepest openings being 800 feet. They were worked as gold properties, but showed an increase of copper in descending which prevented amalgamation and led to the closing down of the property. The Union Copper company is now working several of these veins, one of them, the Big Cut copper vein, yielding considerable ore, which has been shipped. Superficial alteration has rotted and decomposed the upper part of the vein so that it closely resembles the saprolites of the adjacent schists, though redder in color.

This changes in depth to a rusty, earthy, silicious mass, holding carbonates, oxides, and native copper, passing downward into black sulphuret, and this to the unaltered sulphide. These changes are generalized, since there is no definite level of any one kind of ore. Owing to vertical fracturing, the upper and lower limits of the brown stained oxidized ore are very irregular. This is especially true of the lower limit, channels and pipes of oxidizing waters extending down 180 feet or more below the surface and half that distance into solid, unaltered quartz ore. The zone of enrichment marked by chalcocite, in part altered to cuprite, is therefore not well defined, the secondary sulphides being scattered about in accordance with the irregularities of the water line.

At the very interesting copper veins of the Virgilina district of Virginia and North Carolina no evidence on secondary enrichment was obtained, as the quartz veins carry chalcocite and bornite and near the surface the superficial alteration products of these minerals. The deepest shaft is now but 300 feet down, and it will be interesting to see if the glance changes to chalcopyrite in depth. The bornite is seen altered to glance and hematite below the zone of oxidation by the surface waters. This and the general absence of either pyrite or chalcopyrite from the glance are quite unlike other deposits of the east, and, in fact, of the west.

Specimens of glance from the Gila river, Arizona, kindly given me by Mr S. B. Ladd, are similarly free from pyrite or chalcopyrite, but both this material and that of Virgilina are distinctly crystalline and lack the dull fracture and structure of Butte ores. In the "Blackfoot ceded strip," on the east side of the fruit range in northern Montana, dikes of diabase traversing Algonkian slates carry copper ores. The original chalcopyrite is seen cracked and fissured with alteration chalcocite.

SILVER

The "bonanzas" of rich silver ores like those of the Smuggler and Mollie Gibson mines of Colorado, and of silver-lead or pyritic ores carrying ruby silver, polybasite, or silver glance, are believed to be, in many if not most cases, examples of secondary deposition.

The first writer to call attention to secondary enrichment of silver veins is De Launay. In discussing the superficial alteration of silver deposits he gives a summary of his views,* from which the following extract is taken:

> Near the surface the silver in the veins is in the native state, with chlorides, bromides, iodide, etcetera, associated with oxide of iron, manganese, and often of copper. If the gangue is silicious, it shows a porous honeycomb aspect, resulting

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* Ann. des Mines, vol. xii, 1897, p. 221. See also description given in L'argent, p. 96.

from the removal of the sulphides which it formerly held. Frequently, too, the red and gray silver ores are associated there. These ores are the pacos, chlorides, etcetera, of the Spanish-American miners.

Deeper down, at 80 to 150 meters, the bonanza zone is encountered, where the silver is in the form of glance (Ag_2S), the copper as chalcocite, gray copper (often argentiferous), and bornite. Iron is wanting or is present as oxide. Lead, if present, is in small amount and mostly in the form of the carbonate.

Still lower beneath the ground water level, which varies from 400 to 500 meters, one finds a complex assemblage of primitive metalliferous sulphides, galena, which is more or less argentiferous, copper and iron pyrites, arsenopyrite, blende, and rarely silver minerals.

In the secondary ores of copper, gold and silver, which are commonly present in small amounts in copper ores, are concentrated in gray coppers or as native gold or silver, which we see commonly in bornite.*

Professor Vogt also describes † the recent formation of a gold and silver bearing zone beneath the iron hat. He says that in the Rio Tinto region the "iron hat" is from 35 to 50 meters deep, and consists of iron oxide or hydrated oxide, with from 35 to 50 per cent of iron, some silver in part as basic sulphate, and a few ten-thousandths per cent of arsenic, while on the other hand the copper contents are, as already remarked, entirely oxidized and dissolved out. In one mine, North vein number 2, at Rio Tinto, there occurred between the "iron hat" and the underlying comparatively fresh pyrite a layer of earthy, porous material bearing gold and silver. This earthy ore, though a few decimeters in thickness, may be followed continuously over the entire ore body. This very marked layer follows closely the irregular plane between the "iron hat" and the underlying pyrite. It everywhere contains an average gold and silver contents of from 15 to 30 grammes gold and 1.025 silver, with a value of about 150 marks per ton. In stripping off the "iron hat" this earthy mass is carefully laid to one side, and has thus yielded fully a thousand tons of ore. It is clear that the formation of this gold and silver bearing zone is connected with the oxidizing process that formed the "iron hat," and that the gold and silver comes from the very small percentage of such metals in the primary ores.

Another interesting structural feature of silver bonanzas is their occurrence in connection with faults or later fractures. This is also true in the copper mines of Butte, as pointed out by Emmons. It is probably true in the Broken Hill Consolidated mines, Australia, and in the Aspen district, Colorado.

In his monograph on the Aspen district, Colorado, Mr Spurr ‡ describes the occurrence of the famous ore bodies of the Smuggler and Mollie Gibson mines at Aspen. The ore consists of barite and polybasite, with tennantite. Although Mr Spurr gives no definite statements as to the possible secondary origin of these ores, yet the sketch which he gives on page 183 and the descriptions all indicate that the original ore was a silver-bearing lead sulphide, with more or less zinc sulphide, formed along inclined faults, and that subsequent to the formation of these ore bodies nearly vertical faults displaced the ore and formed the two bodies now worked at the mines mentioned. Although in these vertical or nearly vertical fissures rich polybasite ore is now found, it does not extend far in either direction from this fault, and the description of the ores given by Mr Spurr indicates that it is derived by secondary alteration processes from the lead and zinc ore bodies. This also is indicated by the fact that the polybasite is in part altered to native silver at the extreme lower end of the ore body.

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* De Launay, loc. cit., p. 195.

† Zeitschrift für Praktische Geologie, July, 1899.

‡ J. E. Spurr: Monograph no. xxxi, Aspen mining district, U. S. Geological Survey.

In conversation Mr Spurr has admitted the possible secondary origin of these polybasite bodies, but he has no new evidence upon the subject. He says:

> "This ore was of a rich character, having large amounts of polybasite and native silver. This polybasite body appears to lie in a sort of subordinate shoot, trending south of east and lying at the Gibson fault plane. This shoot is marked by exceptionally large and rich bodies of a nature not found elsewhere in the mine. It is noteworthy that this rich shoot is practically the lower termination of the ore of the Gibson fault. Most of the ore below this is native silver, which, from the nature of its occurrence, is manifestly a secondary deposit leached from the rich ore above. Some of these secondary deposits are, however, of considerable size, and empty vugs are often found beautifully and elaborately festooned with delicate wires of silver. Above the polybasite ore, however, the ore appears to be pretty continuous, but the amount of silver becomes less."

It will be noticed that he recognizes the secondary nature of the silver. and that the polybasite lies between the native silver and the lead surface,

In his chapter on the chemical geology of the region, where he discusses the alteration of the ore deposits and of the limestones, he does not adduce any new facts concerning the formation of the polybasite ore, but he does state that iron pyrites carrying small amounts of arsenic, lead, copper, zinc, cadmium, cobalt, and nickel are found, and that tetrahedrite is also very common. The polybasite is said to be later than the barite.

A very interesting and remarkable case of secondary enrichment occurs at the Broken Hill Consolidated mine, Australia, described by Mr George Smith.* Mr Smith shows by his description and sketches that the lode carrying the ore faults earlier veins, and that the lode worked is rich only where such intersections occur. He says: "All the evidence yet produced by the mine's development points to an essential connection between the ore deposits and cross-veins." His explanation of electric currents seems to be unnecessary, but may well supplement a leaching of the earlier vein and the concentration of material at the point shown. It is significant that the ore occurs under the vertical vein, as shown in his figure, and not above its faulted portion.

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* Trans. Am. Inst. Mining Engineers, 1896, p. 69.

The only examples of secondary sulphide enrichment of silver veins which I have carefully studied are those of Neihart, Meagher county, Montana. The Neihart ore deposits occur in metamorphic gneisses of supposed igneous origin and Archean age, and extend upward into the basal beds of the Belt series of Algonkian age. They are sheeted fissures that cut both ancient and recent igneous rocks, and are believed to be of post-Cretaceous age.

The veins contain silver-lead ores; more rarely rich silver sulphides. The ratio of gold and silver is one dollar in gold to 5 ounces of silver. The common ores consist of galena, blende, and pyrite in a gangue consisting of lime-magnesia-iron and manganese carbonate. The rich silver ores consist of polybasite, with a lesser amount of pyrargyrite, and in the oxidation zone of native silver chalcopyrite also occurs. Barite is a common gangue mineral, but occurs in much smaller quantity than the carbonate "spar." The primary ore minerals are those mentioned above, excepting perhaps pyrargyrite. Polybasite more commonly occurs, however, as a secondary mineral.

The silver-lead ores vary from $20 to $60 per ton; the richer ores $100 to $200 or more per ton. The vein fissures are part of a general fissure system, running about north and south magnetic, and dipping west at 60 to 80 degrees. The width of the fissure varies in the different rocks. It is widest in the softer schistose rocks, narrow but sharp cut in the massive diorite, is irregular and narrow in tough and knotty amphibolites, and becomes lost in a multitude of little fissures in rhyolite porphyry.

The veins are commonly zones of closely sheeted rock. This rock is intensely altered and decomposed, and the vein walls practically limit this alteration. The ores occur in more or less persistent streaks of carbonates or "spar," and rarely show quartz in this altered rock or vein matter. The payable ore bodies occur in shoots. Ore deposition was by ascending carbonated waters, producing metasomatic replacement along fissure lines. The veins have suffered later fracturing and secondary enrichment of the zone has occurred at or below the water level, while quartz and barite have been deposited in the open spaces of some of the veins, being usually accompanied by rich silver sulphide ores showing marked crustification.*

The secondary deposition of rich silver sulphides has played an unusually important part in the ore deposits of Neihart, Montana. In these veins it consists of a breaking up or decomposition of the primary ore minerals, chalcopyrite, pyrite, and an impure argentiferous galena, of the lode, and the formation of the rich silver minerals, polybasite, pyrargyrite, with secondary pyrite and blende. These secondary minerals are always found in connection with open water pipes or with post-vein fractures, are often well crystallized, and occur commonly with recent quartz in vugs and along open fractures by which descending waters could trickle downward.

The products of superficial alteration are largely removed, and the zone of gossan or the barren leached lode is less than 50 feet deep, or may not exist. Beneath this leached and impoverished part of the lode there is generally an irregular accumulation (sometimes regular enough to be called a layer) of a sooty, black ore consisting of manganese and silver sulphide, the material often being quite rich in silver. In the rhyolite porphyry, where the veins are not well defined but are a mass of shattered rock, the crevices for 40 to 100 feet or more downward are filled with this material. Where the lode is well defined the secondary antimonial sulphides occur below at first in considerable abundance, but deeper down only in crevices and fissures, partly or wholly lining filled fractures, so that they become less and less abundant in going downward on the vein. There is therefore an unusual enrichment of the upper part of these veins—that is, of what is now the upper part.

The transposition and redeposition of ores with enrichment in silver can be easily conceived to take place by means of water-courses conveyveying the deoxidized surface waters to considerable depths, a common feature in many of our western mines.† The ruby silver of the Trout and Hope mines and the rich sulphides of the Granite Mountain mine, near Phillipsburg, Montana, 2,000 feet below the surface, associated with clear evidence of partial oxidation, are examples seen by me. The very rich ores of the Ruby mine on Lowland creek, near Butte, Montana, and the high grade ore shoot of the Hope mine of Basin, Montana, show geological conditions suggesting a similar origin. Microscopic examinations of thin-sections of the Drum Lummon ore, Marysville, Montana, seem to indicate a secondary origin for the extremely rich silver-gold ores of that lode.

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* The foregoing description is an abstract of a chapter on the Neihart ore deposits forming part of a report on the geology of the mining districts of the Little Belt mountains, Montana. Twentieth Annual Report, U. S. Geological Survey for 1898-'99, part iii, p. 403.

† These water-courses occur at Elkhorn, Montana, 2,000 feet below the surface. That they are the channels of descending waters is clearly proved by the main workings, although the permanent water level of the country is only a short distance below the ground, and the oxidized ores extend down for 600–700 feet only. The rocks are limestone.

In the first few years following the discovery of the enormously rich placer deposits of Montana many discoveries of rich silver-bearing lodes were made. These held enormously rich deposits of silver sulphides and sulphantimonides beneath the shallow layer of oxidized ore; but these enrichment deposits, which led to most extravagant ideas of the future of this region, were soon exhausted, and when the leaner, baser, primary ores were encountered work was usually suspended.

ZINC

The secondary origin of bodies of zinc blende at Leadville, Colorado, has been maintained by Blow,* who, in describing their occurrence there, writes:

> The zinc sulphides are the most widely disseminated and show plainly the result of their more ready solubility than the other sulphides and the redeposition of a large portion of the zinc which has thus been removed from the carbonate ores. This fact is clearly shown in many ways, but most satisfactorily just at the line of transition. The sulphides first encountered are invariably heavy sulphides of zinc, carrying a little iron and very little lead. They have a close crystalline structure and lie in a laminated form, the lines of fracture being nearly vertical. Upon these cleavage planes crystals of cerussite are found, and often a small incrustation of native silver. Such deposits, where first encountered in passing from oxidized to unoxidized ores, are always lowest in silver. In their further extension the zinc gradually grows less and the laminated structure disappears. Beyond this, again, the zinc sulphides appear to predominate along cleavage and contact planes with the gray porphyry or along the lines of minor faults and cracks in the limestone. Such characteristics are also universally observed in other instances besides those of Iron Hill.
>
> It seems probable that a large proportion of the zinc, which was totally removed from the carbonate ores, has been redeposited as a sulphide, and principally just below the line of complete oxidation, by surface waters, and such redeposition has advanced and increased *pari passu* with the limit and extent of such oxidizing action.
>
> As a corollary of the above, it is believed that at the present stage of development in Leadville the sulphide of zinc forms a larger part of the unoxidized ores than will be found in future and deeper exploration.
>
> There is also evidence going to show that the action of alteration and secondary deposition has extended for a considerable distance within the sulphide bodies. In ores of this class the silver values are found concentrated, as it were, with preponderance of either the zinc, lead, or iron occurring in lenticular masses or patches, surrounded by low grade ore, and forming bonanzas of great value. These bonanzas are rarely found near the flanks or sides of the chute, but generally in its center and with no connection one with another.

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* A. A. Blow, in Trans. Am. Inst. Mining Engineers, June, 1889.

The notes by Jenney and Iles mentioned show that secondary zinc sulphide is formed at other localities. The writer has also seen zinc blende as a later formed mineral incrusting fractured primary ore and resting on secondary quartz and pyrite in specimens from Neihart, Montana. This secondary blende differs greatly in appearance from that of the primary ore, being translucent, with well formed individual crystals, while that of the older generation is dark colored, impure, massive, and generally fractured.

Conclusions

From what has been shown it is concluded that later enrichment of mineral veins is as important as the formation of the veins themselves, particularly from the economic standpoint. The enrichment is usually due to downward moving surface waters, leaching the upper part of the vein and precipitating copper, silver, etcetera, by reaction with the unaltered ore below. In many cases the enrichment proceeds along barren fractures and makes bonanzas. In others it forms films, pay streaks, or ore shoots in the body of leaner original ore. In still other cases the leaching, transposition, and redeposition are performed by deep seated uprising waters acting upon the vein.

As a consequence of this, veins do not increase in richness in depths below the zone of enrichment.

The practical bearing of the phenomena described and the deduction drawn from them will, I think, be apparent to every mining engineer and geologist. If my views be correct, the future of many ore deposits is to be judged in the light of these facts, and the value of the mine must not be based on the presumption that the ore will continue in unabated richness in depth.

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FAULT SCARP IN THE LEPINI MOUNTAINS, ITALY

BY W. M. DAVIS

(*Read before the Society December 27, 1899*)

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THE APPROACH FROM ROME

The express trains from Rome to Naples begin their journey with an oblique ascent of the long northern slope by which the ancient Alban volcanic group descends to the Campagna, and thus gain the flat pass near Palestrina, between the old volcanoes and the limestone range on the east. On the way, while crossing the radiating spurs and valleys of the northern slope, fine views are opened on Rome and the Campagna from the embankments, and excellent sections of lava flows and stratified tuffs are shown in the cuttings. In two of the latter the lava beds may be seen in section lying in a broad flat trough of tufaceous shale, and thus indicating that since these lavas were poured down between low radiating ridges on the flanks of the volcano, the ridges have been worn away to produce the existing valleys—an inversion of topography well known to be characteristic of such situations.

The pass by Palestrina is crossed in a long and deep cut by which the summit level is somewhat reduced; then the train begins a rapid descent, and as one looks forward on the right he may soon see the Lepini mountains, a well dissected, plateau-like mass, rising in the distance. As the journey is continued, the mountains are perceived to descend by a strong northeastward slope to the broadly aggraded valley floor of the Sacco, a rich agricultural plain, annually spaded over (plows seem to be unknown) by the laborious peasants of the neighboring villages. Whole families may be seen working together, from grandparents to grandchildren—fathers and mothers, sons and daughters. The railway follows the eastern border of the plain. On looking westward to the mountain base, a distance of about 3 kilometers, one may see a bare rocky scarp, with a height of 30 meters or more, following along the base of the steeper mountain front, above a gentler piedmont slope that descends to the alluvial plain. When this scarp was first seen, on my way to Naples, it recalled very distinctly the little cliffs produced by faulting in the western base of the Wahsatch range south of Salt Lake City, as exhibited to the excursionists of the International Geological Congress of 1891, while under the guidance of Mr Gilbert; so I resolved to have a closer look at the base of the Lepini mountains after returning to Rome.

The villages of Scurgola and Morolo lay close to the line of the scarp near its northern and southern ends, as well as could be seen from the train, with a distance of about 8 kilometers between them. Local railway stations of the same names served as the beginning and end of two excursions on foot a fortnight after my first sight of the place.

Local Geology

Between two visits to the Lepini fault scarp I had opportunity at the office of the Geological Survey in Rome of looking over what has been published concerning the geology of the region in question. The most important articles are by C. Viola,* from whose reports and from the geological map of the district it appears that the Lepini mountains consist of a great mass of Cretaceous limestones, here and there capped with Eocene beds, all uplifted and moderately deformed and separated from the Eocene of the Sacco valley on the northeast by a strong fault trending northwest and southeast, with a dislocation of 1,200 meters or more. Several small Quaternary volcanoes, now extinct, are described on the more southern part of the fault line.

The Mountain Front

A view of the mountain front, as seen from Morolo station, shows the fault scarp along the mountain base very clearly. No account of the scarp will be given in the present section of this article, which deals only with the slope above the scarp.

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* Osservazioni fatti sui monti Lepini. Boll. R. Comm. Geol. d'Italia, xxv, 1894, 152–159.
Le Valle del Sacco, etc. Ibid., xxvi, 1895, 136–143.
Cenne delle osservazioni fatti sui monti Lepini nel 1894. Ibid., xxvi, 1895, 322–325.

If the original uplift of the mountain mass ever produced a great fault cliff, all traces of it are now destroyed by erosion; for the mountain front is today elaborately carved into a succession of huge buttressing spurs separated by great ravines. The stream lines of the ravines, dry at the time of my visits, are, as a rule, unbroken by a sharp descent over rock ledges. The ravine floors are for the most part strewn with waste derived from the converging slopes—that is, the intermittent streams of the ravines have generally reached a graded condition, their slope being just about sufficient to give a carrying power that enables them to deal with the waste that is washed down from above and from either side. Only near the head of the ravines, where the process of grading would be latest completed, are strong ledges and cliffs still bare.

The slopes of the buttressing spurs are also generally well graded in their middle and lower parts to an even angle of descent, and thinly veneered with waste. Olive orchards are cultivated on the lower slopes. It is true that some of the more resistant beds of the nearly horizontal limestones may be traced in more or less continuous outcrops, contouring forward around the buttresses and turning back into the great ravines; but the ledges thus determined are not strong enough to break the general impression of even descent that characterizes the slopes. The front base of each buttress is more or less distinctly truncated by a triangular facet, also of generally graded slope, leaning back from the vertical at about the same inclination as that of the sloping sides of the ravines. The slope of the ravine floors is much less steep than that of the sides; yet their descent is by no means gentle. Taken altogether, the carving of the ravines and buttresses to their existing form means long and patient erosive work, persistently acting with respect to some well maintained piedmont baselevel, a work that must have reached the satisfactory condition of established grades first in the lower parts of the ravines, later in their higher parts, and still later on the tributary slopes of the spurs. If any depressions had originally existed in the piedmont part of the drainage ways, they must have long ago been aggraded by the plentiful waste that has been discharged from the ravines. Continuity of graded descent with decreasing declivity forward from the mountain front should therefore be an assured accompaniment of the normal, undisturbed conditions indicated by the well graded forms of the carved mountain front.

The Rock Fans

A cross-section of any one of the ravines in its middle course shows a V-shaped profile, somewhat rounded at the lower angle; but near the base of the mountain front nearly all of the ravines broaden and their floors become distinctly convex, thus imitating the form well known in alluvial fans, though rarely matched in an eroded surface of solid rock. These convex floors will be called *rock fans.*

Although the existence of rock fans, as appropriate elements of retreating escarpments, especially in arid regions, might have been deductively inferred, no observations of such forms were announced, so far as I have learned, until the appearance of McGee's essay, "Sheetflood Erosion,"* in which rock fans are described as occurring at the base of Coyote mountain, in the arid Sonoran region of Mexico. Several low fans there "have the form of alluvial accumulations, but actually consist of sharply carved mountain rocks, veneered thinly with granitic loam and gravel littered with great boulders" (page 112). The context shows that the fans, like the mountains above them and the plains below them, have been carved out of a once much larger rock mass; and hence it must be concluded that the fan form has been preserved during its retrogression from an earlier position, and that it will be preserved during continued retrogression in the future if no disturbance interferes.

The rock fans of the Lepini front seem to possess essentially the same characteristics as those of the Sonoran region. The rectilinear elements of a fan all diverge from the point where the floor of the ravine widens and changes from concave to convex form, and all the elements seem to possess the same declivity. Veneers of gravel are strewn more or less plentifully over the fan surface, but ledges of bare rock are seen not infrequently. The following explanation is offered to account for these curious forms.

It may be supposed that for a time during and after the general uplift of the mountain mass the scoring of ravines in its northeast front supplied material for the formation of advancing or aggrading alluvial fans on the piedmont surface similar to the aggrading fans that are often seen today in the once ice-filled valleys of the Alps. But there must have come a time when the incision of the ravines reached such a depth that the advance or aggradation of the fans ceased. This would have been when a graded slope was established on the rock floor of the ravines in such a position and at such an angle that the prolongation of its line of descent was tangent to the surface of the fan; then any further degradation of the ravine must cause a degradation of the fan; at first near its apex, but later over a greater part of its surface. The advance of the fan is thus slowly reversed into a retreat. It is difficult at first to conceive of the preservation of a convex form by a retreating alluvial fan; one involuntarily imagines that its surface must be trenched along one or another of its radiating elements; but the difficulty of the problem is lessened when it is remembered that the retreat of the fan must be slow, since it can only follow the degradation of the graded rock floor in the lower part of the ravines. Such degradation cannot progress at a rate at all comparable with that of the incision of a rock-walled gorge by a powerful stream, for the agencies of transportation in the ravine are always taxed almost to the full measure of their capacity by the receipt of creeping and washing waste from the upper walls and the tributary slopes. Moreover, the transportation of the coarser gravels is chiefly the work of intermittent wet-weather streams, which work impetuously when flooded, and then cease working altogether for considerable intervals. Such streams actively erode the upper ungraded floor of the ravines; they very slowly rasp down the graded floor of the ravines, and they distribute the waste to the right and left on the convex surface of their fans, clogging channels and filling slight depressions, as they now follow one radius, now another. At the same time, the fan surface weathers and wastes where not renewed by gravel veneer, and the fine soil thus produced is removed by unconcentrated rainwash.

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* Bull. Geol. Soc. Amer., vol. 8, 1897, pp. 87–112.

Thus always wasting, here or there, the surface is nevertheless always maintained in fan-like form, because any undue depression will be filled with gravel at the next visit of the wandering stream. Regularly continued retrogression, aided by the lateral swinging of the graded streams in the lower part of the ravine, should tend to carry the head of the fan back into the solid rock mass; and it seems as if this condition had been actually brought about in the Lepini mountains. The side slopes of the ravines are undercut near their mouths by the swinging streams, and thus the rock floor of the ravine is widened. The wider it becomes, the more manifest must be the convexity of its surface, especially if the floor be steep, for all the lines of descent must have equal declivity from the point where the widening begins. A considerable fraction of a fan may thus come to be carved in solid rock, and eventually the whole of it may be thus placed, as in the examples described by McGee.

At the base of the Lepini front perhaps a fifth or a sixth of the distance from the apex of a fan to the lower margin of the piedmont slope lies on firm limestone; the remainder of the fan should be sought for in a continuously descending slope on the other side of the Tertiary fault line by which the mountain mass is bordered; and it may be added that just such a continuity of descent is beautifully developed at the base of the Apennines where they descend to the Roman Campagna, as seen northeastward from the train while climbing the flank of the old Alban volcanic group.

The Piedmont Slope

The Eocene strata recognized by Viola in the piedmont slope are for the most part sheeted over by limestone waste, especially near the base of the mountain front; but the general form of the slope is not expressive of well established grades. Although a great amount of limestone waste must have been washed down across the piedmont slope, the expectation suggested above of seeing there a forward extension of the grade exhibited in the ravine floors and in the fans at the ravine mouths is certainly disappointed.

Drainage lines are continued forward from the mountain base, but the interstream surface of the piedmont slope frequently has a jumbled appearance, the adjacent parts not possessing that well organized relation to their drainage lines and to each other which always characterizes an eroded surface that has been everywhere reduced to a graded form under normal, undisturbed conditions. There is no well defined continuation of the fan-like forms that are so well seen in the widened floors of the rock-carved ravines. The irregularity in the distribution of limestone gravel on the Eocene strata may be associated with the irregularity of piedmont form. Instead of being an evenly spread sheet of waste veneering the clays and forming laterally confluent fans—the forward extension of the rock fans of the ravines—the gravels are present here and absent there in rather arbitrary fashion.

Near the spring known as Fontana Varico, just beneath the rock fan of the third ravine north of Morolo, the upper part of the piedmont slope is broken by a little scarp, partly of gravel. Farther forward, near the lower border of the piedmont slope where it is about to descend beneath the alluvial plain of the Sacco, the irregularity of its surface takes the form of uneven mounds. The floodplain, elsewhere perfectly level, is here locally arched in the form of a flat dome 4 or 5 meters high and from 70 to 100 meters in diameter. This interesting point may be reached by a foot path across the fields, directly opposite Morolo station, the most direct approach to the mountain front. The Sacco is here crossed by a little foot bridge. All these local peculiarities of piedmont form suggest that some recent disturbance has replaced the orderly piedmont slopes that should normally be associated with the carved

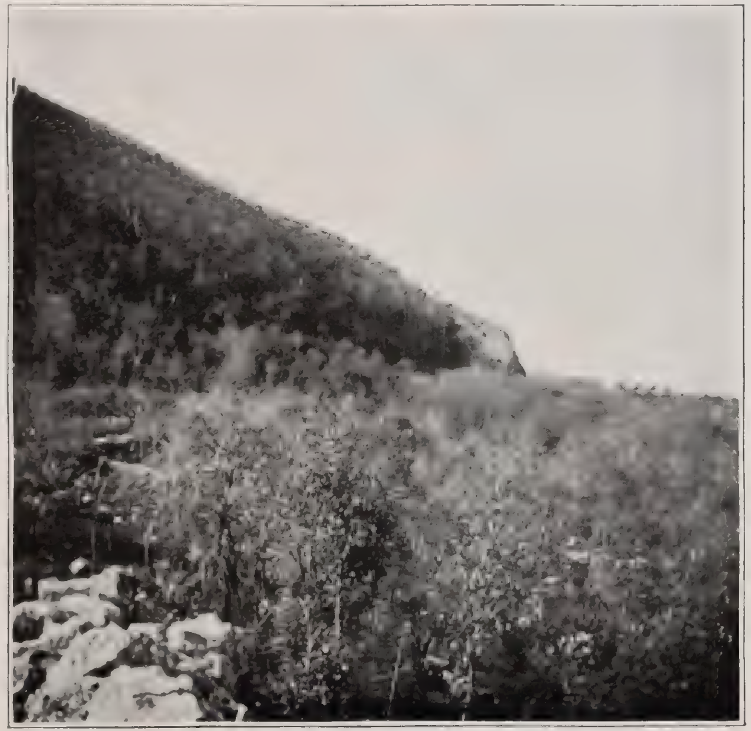

FIGURE 1.—FAULT SCARP NEAR MOROLO, LOOKING NORTHWEST

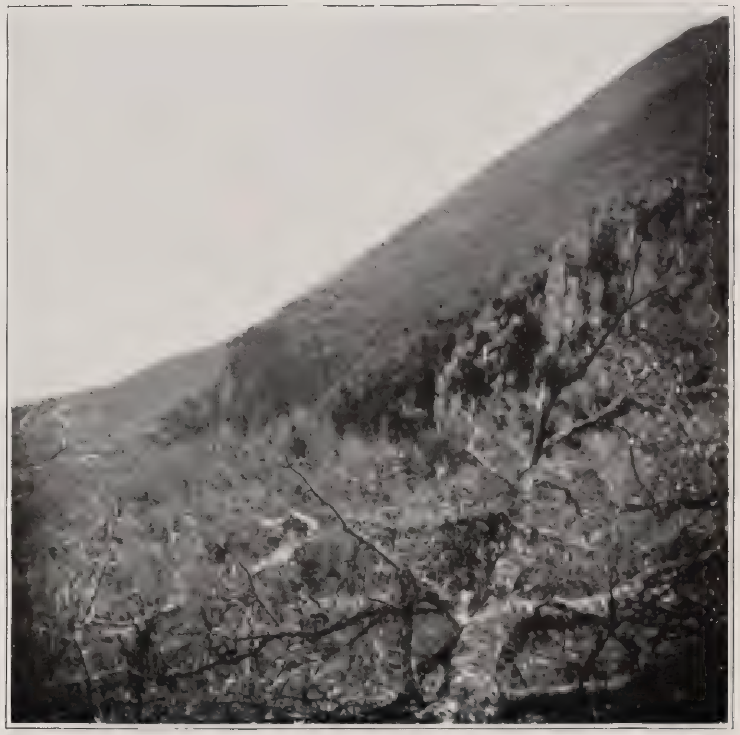

FIGURE 2.—FAULT SCARP BETWEEN SCURGOLA AND MOROLO, LOOKING SOUTHEAST

FAULT SCARPS IN THE LEPINI MOUNTAINS, ITALY and graded front of the mountains by the less orderly forms that characterize the piedmont slope today.

The Fault Scarp

The well carved mountain front and the uneven piedmont slope are separated by a line of low cliffs, here interpreted as a fault scarp. The location of the cliffs on or close to the line of strong faulting, shown by Viola to separate the Cretaceous mountain mass from the Eocene piedmont slope, is very suggestive of dislocation ; and the freshness of the cliffs shows their origin to have been recent, much more recent than the great dislocation in consequence of which the mountain front was exposed to the forces of denudation and elaborately carved into buttresses and ravines. The cliffs are not perfectly continuous or of uniform height ; they weaken in some places to ledges of only 10 or 15 meters ; they rise in crossing some of the rock fans to bold walls 30 or 40 meters high. Their line of extension is comparatively straight between Scurgola and Morolo, but it is sometimes locally divided into several branches, each marked by low scarps. Where the cliffs are highest nearly all the recent dislocation seems to have been accomplished on a single plane of movement. In a few places shortly south of Scurgola there is an appearance of fault scarps on the mountain front 50 or 100 meters above its base, the distinction between these supposed fault faces and the normal outcrops of ungraded ledges being that while the latter follow the stratification, contouring forward around the buttresses and returning into the ravines, as already stated, the former follow a nearly vertical plane, and therefore rise and fall in passing the salient front of a buttress. All these minor features are, however, but natural complications of the main scarp, by which the graded slopes of the mountain front are broken at their base into a precipitous descent to the piedmont slope. When seen in profile (plate 18, figures 1 and 2), the discontinuity of the slopes is often very marked ; it is much stronger than the steps caused by any outcropping, ungraded ledges in the lower or middle part of the mountain front, and is possibly equaled only in the stronger cliffs of the mountain tops. Most striking is the prevailing increase in the height of the scarps as they pass in front of the ravines, where the arched cliff tops display to a nicety the convex form of the rock fans. The cliff beneath the third ravine northwest of Morolo is the finest example of this kind; it is pictured from the front and side in plate 19, figures 1 and 2. The scarp persistently increases in strength while passing the ravines. It may be concluded from the varying height of the cliffs and the irregular forms of the piedmont slope that the recent faulting, or at least the inequality of its movement, is to be explained by an irregular depression of the piedmont Eocene mass rather than by an uneven elevation of the Cretaceous mountain block. No sufficient explanation has occurred to me for the systematic irregularity of dislocation, whereby its greatest measures lie on the lines of the ravines.

The suggestion that the line of basal cliffs is due to the outcrop of particularly resistant members of the Cretaceous limestones deserves special consideration, for cliffs of such origin are much more common than fault cliffs. Outcrop cliffs are well known in many dissected plateaus, such as the Allegheny plateau of West Virginia, where the hillsides are in general reduced to a tolerably constant angle of slope,* yet where the slope is frequently broken by cliffs that mark the outcrop of resistant sandstone layers. Such cliffs always retreat from the front of the spurs or buttresses into the ravines; it is the constancy of this familiar relation that establishes the general principle that erosion is more rapid on the trough line of a concave ravine than on the slope line of a convex spur. But the basal slope of the Lepini are abnormal in being least graded in front of the ravines and most graded at the base of the spurs. Furthermore, if the cliffs were the result of normal denudation, the ravines should contract to narrow gorges in passing through the controlling hard strata instead of opening to convex fan surfaces. But all consideration of excessive hardness in the basal strata is here irrelevant, for the limestones are of essentially the same quality for hundreds of meters upward from the mountain base. The lowest exposed layers have no such excessive strength as to have resisted erosion through the long period during which the ravines and slopes above them were so well graded. The sudden break at the base of the ravines in particular admits of no explanation save by a recent dislocation, presumably located on or near the ancient line of fracture by which the mountain mass was originally delimited.

Some of the rock fans are newly and narrowly trenched by the streams that formerly ran contentedly forward upon their sloping surface. As far as observed the trenches are sharp-cut gorges, not yet graded on their floors, and enclosed by steep and bare rock walls. The depth of the gorges decreases rapidly upstream, as in the fourth and fifth ravines northwest of Morolo, and their heads are not yet, as far as I examined them, cut back to the apex of the rock fans. The fine fan shown in plate 19 is practically untrenched, probably because of the underground

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*See the plates in Campbell and Mendenhall's paper, Seventeenth Annual Report (pt. II), U. S Geological Survey.

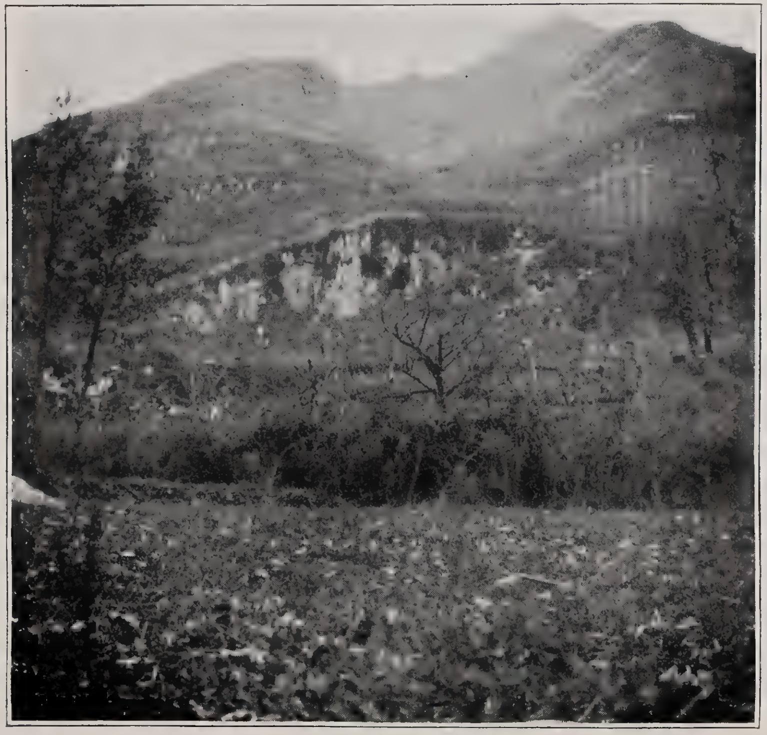


Figure 1.—Fault Scarp crossing rock Fan near Morolo, looking Southwest

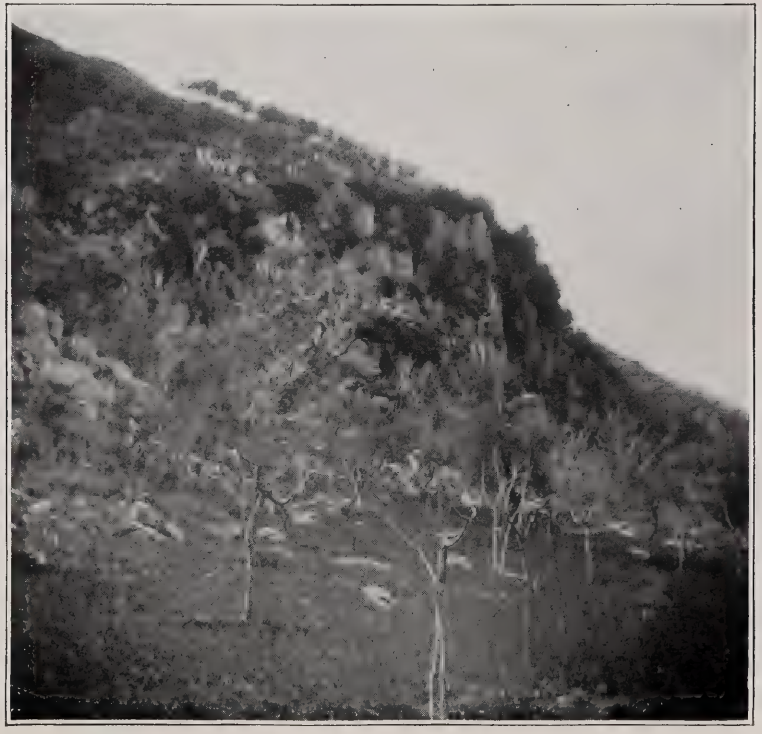


Figure 2.—Profile View of fault Scarp crossing rock Fan near Morolo, looking Northwest

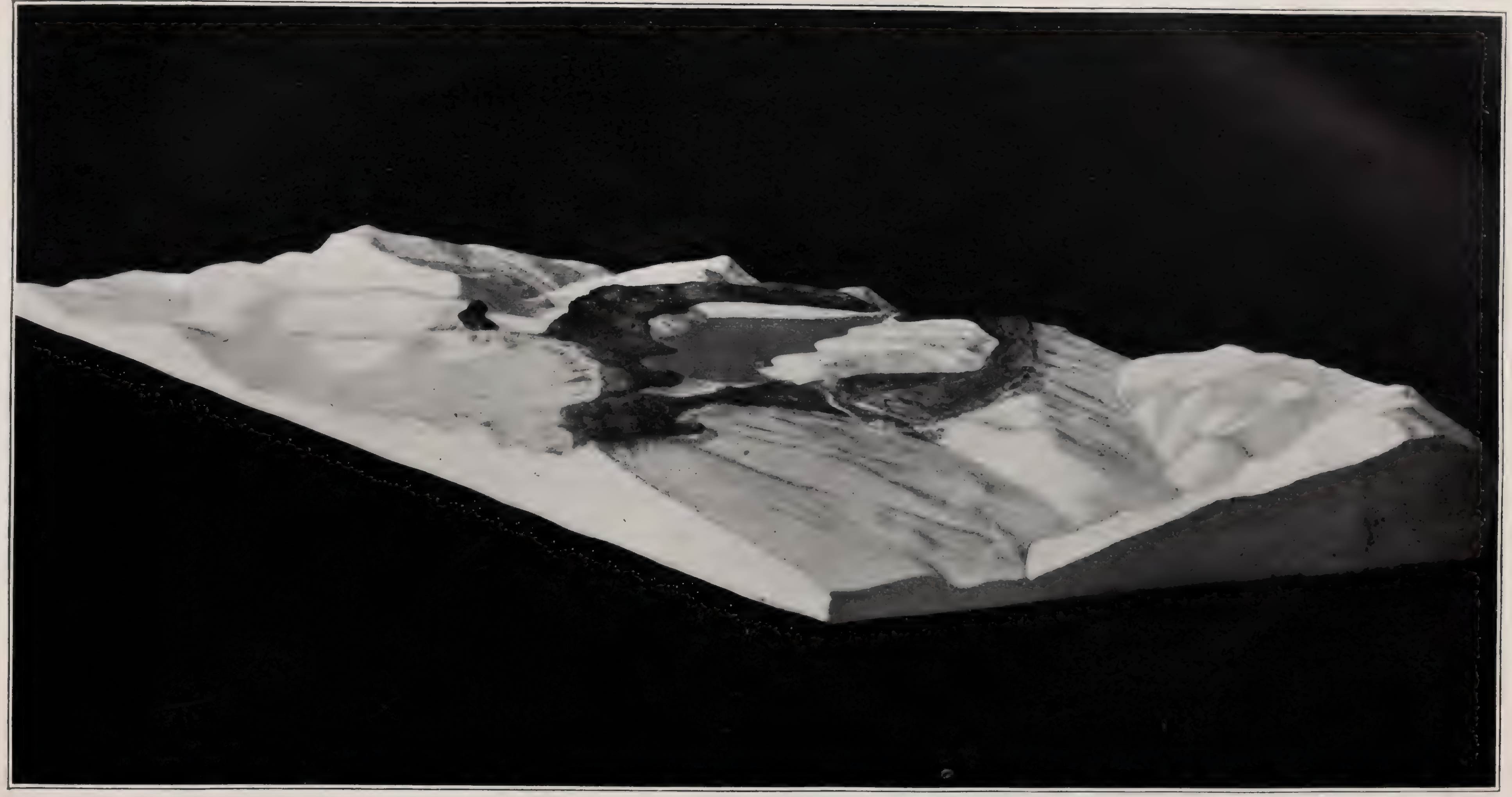
FAULT SCARPS IN THE LEPINI MOUNTAINS, ITALY

passage of water from the upper ravine, to emerge in Fontana Varico, near the base of the scarp.

The village of Morolo is situated on a sloping limestone platform that seems to be the result of the confluence of two rock fans just beneath a narrow buttress that separates their upper portions. An old castle stands on the front ledges of this buttress. The fault scarp seems to pass just east of the village, but it is not so strong here as farther northwest, and it is somewhat concealed by the large trees of old olive orchards. Southeast of the village, across the ravine by which the highway winds up in a roundabout course from the floodplain of the Sacco, the next succeeding spurs of the mountain front descend to the piedmont slope in long, unbroken catenary curves, thus proving that the recent dislocation ceases near Morolo. Near the other end of the fault scarp, Scurgola is built on a limestone promontory that advances in front of the cliff line and rises in picturesque form over the piedmont slope, thus implying that the boundary between the older and younger formations is here not so closely coincident with the line separating the mountain front and piedmont slope as it is on the stretch between the two villages; but this matter needs much more study than I was able to give it. Just back of Scurgola the line of dislocation is indicated by a depression across a limestone spur, a form that is singularly inappropriate, as the product of normal degradation is a mass of nearly horizontal strata, but perfectly appropriate to degradation along the path of a fracture. The mountain front further to the northwest was hidden by this spur, so that I am unable to say anything of the extension of the scarp in that direction, except that, as looked for from the railway, the scarp, if occurring there at all, was certainly less conspicuous than between Scurgola and Morolo.

Fresh fault scarps along the base of mountain ranges are so rare among topographic forms that fuller study of this small example is to be desired. At the time of my two visits trains leaving Rome and returning were so arranged as to give only about six hours on the ground, and this did not suffice for more than a hurried walk along the scarp and a climb to some of the rock fans.

The villages are primitive, picturesque in the distance, very unattractive on closer inspection, and without accommodations for travelers. The villagers were as amiable in replying to my questions as they were inquisitive over the unusual sight of a stranger. Visitors who do not find the very simplest diet sufficient should carry lunch with them. The narrow road between the villages along the upper part of the piedmont slope is impassable to wheeled vehicles, its surface being often cluttered with loose blocks of limestone, worn smooth and slippery by long use. The highways from the railway stations to the villages are well constructed, but the one between Morolo station and the village makes a circuitous detour to the south. The path almost directly opposite Morolo station (a little south), crossing the Sacco by a foot bridge and leading over the alluvial fields to the uneven forms at the base of the piedmont slope and thence up to the largest of the broken rock fans over Fontana Varico, is the best route for a single excursion to this interesting locality.



MODEL OF CAMASLAND, VIEWED FROM THE NORTHWEST

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CAMASLAND: A VALLEY REMNANT*

BY GEORGE OTIS SMITH AND GEORGE CARROLL CURTIS

(Read before the Society December 27, 1899)

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INTRODUCTION.

Camasland is the local name of a high valley in central Washington. Its peculiar features have rendered this valley well known to all the people of the region, and as a somewhat unique topographic form it deserves description.

Camasland is situated on the eastern slope of the Cascade mountains, in the northeastern part of Kittitas county, and is included within the boundaries ot the Mount Stuart quadrangle, which has been surveyed both topographically and geologically by the United States Geological Survey. Professor I. C. Russell visited Camasland in the summer of 1897, in the course of a reconnaissance of the Mount Stuart area, and called the attention of the authors to this topographic feature when they entered upon the detailed survey of the quadrangle the following year.

The relief model, a photograph of which illustrates this paper, plate 20, was made by Mr Curtis, and is based on the topographical map. Details were supplied from observations, photographs, and sketches made in the field. The scale of the model is 1 : 11787, or about 5½ inches to the mile, sufficient to permit all the suggestive features to be shown without vertical exaggeration. Even the houses, and the roads which wind up to this high valley, have been indicated on the model.

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Topography

In its general form Camasland might be compared to a platter, bottom side up, since it is a flat elliptical plain, lying within a comparatively low rim, but high above the surrounding country. The level floor of the basin, as can be seen in plate 20, is irregular in outline, and about two miles long by one-half mile wide. The rim inclosing this plain rises at one point 600 feet above the valley floor, but averages about 350 feet. It stands, however, from 1,000 to 2,000 feet above the surrounding valleys. A bold cliff extends with few breaks along the outer margin of this rim, with steep talus slopes from the base of the escarpment to the streams in the canyons below.

The surrounding region is one of mature dissection, the valleys being deep and the ridges cut to knife-edge divides, thus leaving no trace of preexisting topography. The contrast, then, is marked between this level valley of Camasland, with the gentle rise to the inclosing rim, and the rugged country lying outside that rim. Thus Camasland is truly an oasis among the rugged barren mountains.

The valley floor, which presents an appearance of being perfectly level, is, however, over 100 feet higher at the southern end than at the outlet, this being a grade comparable with that of the floodplains of the larger streams in the region. The outlet of Camasland is through a narrow cut in the rim on the northwest side. Within this barrier, as may be seen in the illustration of the model, only a tiny stream is visible, there being at present a mere succession of shallow holes, or at best a small brook struggling to reach the outlet. Beyond the rim Camas creek continues down to Peshastin creek, its waters being materially augmented by a tributary stream from the southwest. This tributary discharges a considerably greater volume of water, but the difference in the valleys of the trunk stream and of the tributary is both striking and suggestive. The valley of the former is wider and its slopes are gentle, and pot-holes are common along the stream channel, while the tributary flows in a rugged, narrow, canyon-like valley.

Geology

FORMATIONS

Names and relations.—Three formations occur within the Camasland area—sandstone, diabase, and alluvium. These are represented in the accompanying illustration. The sandstone is the country rock, and the diabase forms the rim of the basin within which the alluvium is shown.

Sandstone.—The sandstone is an important formation in this region, extending to the north and east into the valley of the Wenache river and westward to the crest of the Cascade mountains. It has been given the name of the Swauk sandstone from its occurrence in the Swauk mining district, southwest of Camasland. Its age is Eocene, as determined from abundant fossil plants found in the valley of the Swauk and on Tiptop, the peak in the southwestern corner of the area here considered.

The Swauk sandstone in the vicinity of Tiptop is a gray arkose, with associated shaly beds which are leaf-bearing. At Camasland and extending eastward the sandstone is white and consists of clean quartzose material. It is massive and not plainly bedded, except where a few thin beds or lenses of quartz pebbles occur. Where the topography is not bold, as within the rim of Camasland, the sandstone is rarely well exposed, but a mantle of quartz sand covers the surface, and only occasionally are smooth bosses of the massive sandstone seen.

Diabase.—The igneous rock of Camasland is a diabase, light gray to brownish gray in color and of varying texture. Its constituent minerals are labradorite, augite, olivine, and magnetite, while its chemical composition is close to the average for members of the gabbro-diabase-basalt family. For the most part this rock has the ophitic or diabasic texture, but variations from this type occur. Thus on the one side the rock becomes more or less granolitic in texture, and on the other it often approaches the basaltic texture, becoming finer grained and at times even glassy. These textural changes are quite definitely connected with the thickness of the intrusive sheet of diabase. The diabase commonly weathers into large, rounded blocks, which constitute a noticeable detail of the topography.

Alluvium.—The third formation is the alluvium which forms the surface of Camasland itself. This is a rich loam at the surface and contains a considerable amount of organic matter. The few exposures of the subsoil reveal a fine silt with few pebbles. This alluvium covers an area of about one and a half square miles, and its fertility is such as to attract several ranchers, who live in Camasland during the summer months.

STRUCTURE

The sandstone in the vicinity of Camasland has participated in the general folding of the region. In the southwestern portion of the area here considered the beds are steeply inclined, and on Tiptop are even vertical. Camasland itself is in the trough of a gentle syncline, the axis of which has a northwest-southeast trend. Observations of dip in the massive sandstone are not easily made, but are sufficiently numerous to clearly indicate this synclinal structure.

The structure of Camasland is, however, more clearly shown by the outcrop of the sheet of diabase, which has been folded with the sandstone. The intrusive nature of this sheet was conclusively determined from a study of its upper and lower contacts with the sandstone. Wherever the dip of the sandstone could be observed the sheet of diabase was seen to be conformable, except at one point on the northeast side, where the diabase breaks across the sandstone and connects with a smaller sheet at a lower horizon. The latter sheet is not of great extent and might be better described as a tongue which soon thins out.

The synclinal basin is spoon-shaped, the point being on the northwestern side. Here the dips are very gentle and the diabase sheet is thick. At the southwestern end of the basin the sheet had apparently less thickness. Exact measurements of the intrusive sheet are difficult to make, but approximately the diabase may be said to vary from a few feet, as in the lower sheet or tongue, to over 500 feet on the northwestern side of Camasland.

The exposures of sandstone within the basin defined by the rim of diabase are not numerous, but fortunately they are sufficient to clearly indicate the conformity of the beds above the intrusive sheet with those below. There is little or no metamorphism of the sandstone at the contact with the diabase, a feature doubtless due in part to the pure quartzose character of the sandstone. At a few points, however, apophyses of the intrusive rock extend for a short distance into the adjoining sandstone. Only one large dike, however, occurs in the vicinity of Camasland, and the connection of this with the sheet could not be traced. This absence of dikes is somewhat remarkable, since a few miles distant the Swauk sandstone is cut by hundreds of diabase and basaltic dikes.

ORIGIN OF CAMASLAND

The topographical and geological observations recorded above suggest an explanation of this exceptional feature in a region of mature dissection. Camasland, standing high above the surrounding canyons, is in reality a remnant of a former topography, and the alluvium-floored basin owes both its origin and its preservation to the occurrence of the intrusive sheet of diabase.

It would be difficult to restore the older topography from this small portion that remains. The topography of this part of the northern Cascades region has attained such maturity that as yet too few traces of earlier topographic features have been detected upon which to base even conjectures as to the extent to which erosion was carried in preceding cycles. A few deductions from the observed features of Camasland may, however, be made and its history at least partially traced.

The width of the lower valley of Camas creek has already been mentioned as seemingly out of all proportion with the present small stream occupying it. This with the width of Camasland itself warrants the inference that it is a valley remnant. The determining factor in the history of this old valley is the diabase sheet, the present extent of which is shown in accompanying plate 20. Its original extent can not be determined, except that the intrusive sheet is not found elsewhere in this area of folded sandstone.

It may be supposed that the earlier Camas creek, flowing from the south, many miles beyond Camasland, along the general strike of the sandstone, cut down until it suddenly found itself superimposed on this much harder rock. Thus at two points in its course a barrier was encountered, which became more and more formidable as the cutting proceeded. Two local baselevels were formed, the one on the upper course of the stream and the other above the present outlet of Camasland, the latter the more important and in reality controlling the whole upper portion of the stream. This interruption in the work of general degradation by the upper portion of Camas creek gave the neighboring tributaries of Mission creek a decided advantage. The latter stream having less to obstruct its course down to the Wenache river, capture by the Mission drainage was inevitable, as its branches cut their way back to the relatively high valley of Camas creek. The elbow of capture is situated about two miles south of Camasland, where the stream from the south makes an abrupt turn to the east in a canyon 800 feet deep. A portion of Camas creek below this point of capture was obliged to gradually reverse its direction of flow until as an obsequent stream it has worked back, capturing another important tributary of Camas creek. Now steep cliffs bound the Camasland plateau on the south, and the divide is established on the diabase rim.

Before this diversion of the headwaters of Camas creek had been effected the waters flowing across the upper diabase barrier had formed an extensive floodplain at a level established by the lower barrier, and this is the alluvial plain preserved today. This period in the history of Camasland was of considerable duration, as is shown by the depth and width of the gap cut in the hard diabase at the upper end of Camasland, where the alluvium extends to the very brink of the cliff. It is noticeable that already the obsequent drainage has begun to cut into the diabase sheet, and capture of the Camasland drainage will doubtless continue, since the greater thickness of the diabase sheet at the northern end where it is crossed by Camas creek gives the pirate stream a decided advantage. As Camasland is underlain by the sheet of resistant rock, it is a relatively permanent land-form in consequence of the geologic structure, and after the thin alluvial filling is more or less swept away through a lower outlet to the south, it seems probable that Camasland will still remain as a mesa—high above the surrounding country.

By reason of its geologic structure, then, Camasland presents a fine example of a valley remnant. So perfect is the preservation that even so delicate a feature as the floodplain of fine alluvium has resisted erosion. Such an exceptional and at the same time complete interruption of stream processes causes Camasland to afford a strong contrast to the mature topography of the surrounding region, where stream work has progressed further. The model figured in plate 20 thus illustrates two stages in drainage history, and presents an example of past as well as of present work by streams.

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TERTIARY GRANITE IN THE NORTHERN CASCADES*

BY GEORGE OTIS SMITH AND WALTER C. MENDENHALL

(*Read before the Society December 30, 1899*)

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INTRODUCTION

The area to be discussed in this paper is in the immediate vicinity of Snoqualmie pass in the northern Cascades. Snoqualmie pass is in central Washington, about 10 miles north of where the Northern Pacific railroad crosses the range. It is a low pass, less than 3,100 feet above sealevel, and is the only point in the state where the range is crossed by a wagon road. On all sides of the pass, however, rugged peaks rise to elevations of from 5,700 to 6,300 feet. Although the geologist finds that this bold topography prevents rapid progress, while the luxuriant vegetation of the western slope at times presents almost impassable obstacles, yet the rock exposures in the higher parts of the range are such as to furnish conclusive evidence as to their character and relations.

In the summer of 1895 Snoqualmie pass was visited by a United States Geological Survey party under Mr Bailey Willis, with the senior author of this paper as his assistant. The work was of the nature of a rapid reconnaissance along the northern Cascades, yet during the brief stay in the pass sufficient was seen to suggest the hypothesis that the granitic rock here might be younger than the black slates, which contain fossil plants. During the season of 1899 this area was visited by the authors in connection with the survey of the Snoqualmie quadrangle. Detailed mapping has afforded opportunity for the observation of facts which conclusively prove the intrusive character of the granite. This determination of the age of the granitic intrusion is of value and interest in the bearing it has on the history of the northern Cascades.

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General Geology

SEDIMENTARY ROCKS

The sedimentary series exposed in Snoqualmie pass includes slates, sandstone, and conglomerate. The slates are the most important and cover large areas. They are black or green, in the former case being quite carbonaceous. Occasionally the slate has an irregular schistosity and is knotted and crumpled, or it may become very silicious and felsitic, so as to closely resemble a hornfels.

The sandstone occurs at a few localities bedded with the green slate and is in part a white sandstone, only fairly well cemented, and in part a very quartzitic sandstone. A thin bed or lens of gray limestone also occurs at one point associated with the slates.

Beds of conglomerate in the black slate are quite noticeable along the county road in the pass itself. It is of striking appearance, quite resembling a volcanic breccia. The angular fragments, however, are all of sedimentary rocks, with one possible exception. Black chert is abundantly represented among these pebbles.

The occurrence of fossil plants in the Snoqualmie Pass section is of great importance to the geologist, although the matrix of these fossils is not at all encouraging to the collector. The black slate here has little cleavage developed and often breaks with a conchoidal fracture. The material collected in 1895 by Mr Willis, however, afforded sufficient basis for the determination of the series as Tertiary and probably Miocene. Professor F. H. Knowlton's report on the collection was as follows:

"I recognize four species of fossil plants, as follows:

Platanus dissecta Lesq.
Acer æquidentatum Lesq.
Ficus n. sp.? cf. *F. artocarpoides* Lesq.
Cinnamomum n. sp.

"The first two species are without question Miocene. The Ficus approaches quite clearly to *F. artocarpoides*, which is from the Fort Union group (Eocene) of Montana. The specimen is not perfect, and can not therefore be positively determined. If it differs at all from the Fort Union species it must be very little. Yet it may prove to be new.

"The Cinnamomum is undoubtedly new and a fine characteristic species. It does not approach any described species very closely, yet appears to be of a Tertiary type. . . .

"The two species that can be determined are Miocene and the other two are of Tertiary, probably Miocene, facies."

VOLCANIC ROCKS

Two types of volcanic rock occur within the area here discussed. Of these one is andesitic and the other rhyolitic, and both have beds of pyroclastics associated with the lavas. The andesitic rock is of great areal extent to the south and east of the pass. The work of the past season was not sufficient to fully determine the relations of these volcanic rocks, but it seems evident that they are younger than the sedimentary series just considered. Their relation to the great basaltic eruptions of this region will furnish one of the many interesting problems in the study of Cascade geology.

PLUTONIC ROCKS

It may seem more logical to discuss this class of rocks before the volcanic rocks, but in this case the order adopted will be seen to be the natural one. The plutonic rock is for the most part of a granitic character. In the field it has been termed a granite, and the name is here retained. The rock, however, is rather of the intermediate type so important in the Sierra Nevada region, and later petrographic study may show it to be either a quartz monzonite or a quartz diorite. In general appearance it is quite granitic. Quartz is abundant; both plagioclase and orthoclase are present, the latter being, however, rather less important than in a typical granite, while hornblende and biotite are of approximately equal importance. In the central portion of the mass this rock, provisionally termed granite, is quite homogeneous in texture and of medium grain.

More basic phases of the plutonic rock occur, and these are rocks plainly dioritic in composition. An excellent exposure on a glaciated rock wall showed the granitic and dioritic phases to intermingle in the most intricate fashion. The contemporaneous origin of the two was conclusively shown, and any attempt to separate them would be as futile as it is unnatural.

The intrusive nature of the granitic mass is shown by two classes of evidence—the areal distribution of the granite and the contact phenomena.

Distribution of the Granite

AREAL EXTENT

The granite occurring within the limits of the Snoqualmie quadrangle is simply the southeastern border of a large mass, which extends for some considerable distance both to the west and to the north. Its extent in the Snoqualmie quadrangle where it has been mapped is about 10 miles east and about the same distance south of the northwestern corner. This mass of plutonic rock undoubtedly covers an area measuring not less than 100 square miles in extent. It is therefore an important element in the architecture of the Cascade mountains.

DIKES

Within the area studied there is one apophysis from the granite mass which is more than one mile in length. Another dike in the same part of the area is less regular in character. While only a few hundred yards in width for a mile or more, it swells out into boss-like masses of granite at two points, these masses being about a mile in diameter. The whole body thus roughly resembles in outline a dumb-bell, and is connected by a narrow apophysis to the main mass. A third dike of granitic rock extends up into the overlying andesitic lava, and thus clearly shows the relative age of the volcanic rock and the plutonic. Smaller dikes occur both along the contact and at some distance within the areas of sedimentary or of volcanic rock. In several cases the connection of dikes of this latter class with the main granite mass has not been traced, though such connection probably exists.

The rock of these dikes is a granite porphyry—fine grained for the most part and very rich in quartz. The abundant bipyramidal quartz phenocrysts with the almost felsitic groundmass makes this porphyry a noticeable rock in the field.

Contact Metamorphism

ENDOMORPHIC PHENOMENA

The textural variations within the granite mass offer strong evidence of its intrusive nature. At a distance of 2 miles from the contact, as on Denny mountain, the granite is of medium grain and shows the typical granitic texture. As the contact is approached, however, a gradual change in the texture of the rock is noticed. As a whole the granite becomes finer grained, while the quartz becomes a more conspicuous constituent. The variations are gradual, until at or near the contact the rock is a granite porphyry, with blebs and phenocrysts of quartz, both abundant and prominent.

The rock of the dikes and apophyses from the main mass is a granite porphyry, as has been stated above. Indeed, the porphyry so closely approaches the rhyolitic type that in certain occurrences the dike rock is with difficulty distinguished from the effusive rock which occurs at other points associated with pyroclastics.

METAMORPHISM OF THE SEDIMENTARY ROCKS

Eocene and Miocene strata occurring in adjacent areas in the Cascade region show few traces of metamorphism. The sandstones may be loose and friable, or with the associated conglomerates and shales they may have been consolidated to such a degree as to form bold escarpments thousands of feet in height; but even where intruded by countless basaltic dikes, these Tertiary sediments can not be said to be metamorphosed. In the Snoqualmie Pass area, on the other hand, the sedimentary rocks, though also of Tertiary age, appear much older. Their stratification is generally difficult to determine. The shale becomes a compact and flinty slate, while the sandstone has often the glassy and dense character of quartzite.

More striking even than these lithological characters of the rocks is their influence upon the topography. So bold are the peaks composed of these Tertiary slates and sandstones that it is usually impossible to distinguish them from the topographic forms cut out of the jointed granite and even harder granite porphyry. Sharp needle-like details of a crestline may indicate either the sedimentary or the igneous rock. Neither is the appearance of the talus bordering the steep slopes any criterion as to the nature of the rock forming the cliff above.

This metamorphism of the sedimentary rocks is, in part, of a dynamic character. The presence of well developed joint planes has much to do with the resemblance of the sedimentary rocks to the granite, as expressed in the topographic forms developed; yet the greater part of the metamorphism appears to be traceable to the intrusion of the granite, since it is in this contact region that the characters described above are best developed.

Furthermore, bordering the area of the granitic rock there is what may be termed a contact zone. As the contact is approached from the area of sedimentary rocks the increase in degree of metamorphism is quite apparent. The rocks gradually lose their original characters, becoming either schistose or felsitic. At one place the carbonaceous slate has become a gneissoid rock, the black layers alternating with irregular bands of quartz and feldspar.* This impregnation appears to have been effected by aqueous agencies, and hence the banded rock is not a true injection gneiss; yet both the added material and its aqueous solvent doubtless had their source in the mass of granite magma intrusive in these sedimentary rocks.

Along the contact itself epidote and garnet are found in abundance. The latter mineral occurs both massive and in crystals, and in its massive state the garnet is found in bodies of considerable size. Tourmaline also occurs in the usual association with quartz in the vicinity of the contact.

Structure

SEDIMENTARY ROCKS

The attitude of the sedimentary rocks in itself furnishes additional evidence as to the intrusive character of the granite, and also shows the nature of that intrusion. The slates and sandstones are strongly folded, dips are mostly steep, and sudden changes in both strike and dip are common. Within the area here described the metamorphism often obscures the stratification, but a sufficient number of observations could be made to show the general relation of the stratified rocks to the granite mass. The strike in a few places parallels the contact, but more frequently it maintains no definite relation. The large apophysis of granite, with the two boss-like enlargements mentioned above, cuts directly across the strike of the slates, which here have a generally vertical dip. In the other places the sedimentary strata present a steep dip toward the adjoining contact.

NATURE OF INTRUSION

The facts just cited are sufficient to prove the independence of the structure in the stratified rocks. The intrusion, therefore, was of a batholithic rather than laccolithic nature. An interesting point in connection with Cascade geology would be a determination of the maximum elevation attained by this granite mass at any time during or since its intrusion. At present the granite is known to make up some of the higher peaks of this portion of the range. The amount of cover under which this batholith consolidated can not be more than conjectured from the facts now in hand. On the summit of Denny mountain, 5,766 feet above sealevel, the granite is a rock of medium grain, showing none of the textural variations that are seen on the northeastern slope of this peak at a distance of half a mile from the contact with the sedimentary rocks. At another locality, at the southern base of Huckleberry mountain, the granite preserves its uniform texture close to the contact, while a dike extending into the overlying rock shows the usual change in texture. Here the cover of volcanic rock is at present about 2,000 feet in thickness, and it is not thought that its thickness ever exceeded 3,000 feet. The physical character of the rock under which the magma consolidated is doubtless a factor that renders the problem a far from simple one when the attempt is made to ascertain the conditions attending this late intrusion of granite.

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* Sixteenth Ann. Rept. U. S. Geological Survey, part 1, p. 667.

Granitic rocks similar to that here described are known to occur along the crest and western slope of the Cascade mountains as far north as the International boundary, and also as far south as Mount Rainier.* At the latter locality an old granite ridge forms an elevated platform, on which rests the volcanic cone. The Rainier volcano is relatively so recent that these relations do not preclude the possibility of correlation of the granite with that described above.

On the eastern slope, in the quadrangle adjoining this on the east, the Mount Stuart granodiorite is known to be of pre-Eocene age, and this granitic rock is also of probable areal importance to the north and northeast.

The Mount Stuart granodiorite forms the core of the Wenache mountains, an extremely rugged range transverse to the general trend of the Cascade mountains. This rock is intrusive in serpentine and other pre-Eocene formations, and here also the intrusion appears to be of a batholithic nature. These two granitic rocks are quite similar in general composition and appearance, and the Mount Stuart granodiorite exhibits no gneissoid structures that would indicate its greater age. The two intrusions, the one of late Tertiary and the other of pre-Tertiary age, must, however, be separated in the geological study of the northern Cascades. Together they are believed to constitute perhaps the most important geologic feature in this range, and as such they must be taken into consideration as the growth of the Cascade range is traced.

RÉSUMÉ

The granitic rock of Snoqualmie pass is intrusive in sedimentary rocks of Tertiary age. Its intrusive nature is made evident by the dikes breaking across the strata, by the contact metamorphism of the leaf-bearing rocks, and by the independence of the structure of the stratified rocks and the intruded mass, which has the character of a batholith.

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*18th Ann. Rept. U. S. Geological Survey, part II, p. 422.

Granitic intrusions of a like nature play an important role in the northern Cascades and belong to two distinct epochs of igneous activity, one being pre-Eocene, the other late Tertiary.

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RELATIONS BETWEEN THE OZARK UPLIFT AND ORE DEPOSITS

BY ERASMUS HAWORTH

(*Presented before the Society December 30, 1899*)

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INTRODUCTION

For a number of years my attention has been called to the coincidence in location of the principal ore deposits of Missouri, Kansas, and Arkansas with the border areas of the Ozark uplift.

GEOGRAPHY OF AREA

LOCATION OF DOME

This dome in a general way occupies an elliptical area about twice as long as wide, with a major axis 250 miles in length, extending from a point in the eastern part of Indian Territory north of the Arkansas river northeast to the vicinity of Bismarck, in Saint Francois county, Missouri. The periphery of the elliptical area passes through the extreme northeastern part of Indian Territory, thence northeast into Missouri by way of Jasper, Dade, Hickory, Morgan, Cole, and Franklin counties, and swings around to the east and finally back to the southwest through Washington, Saint Francois, Madison, Reynolds, Shannon, and Howell counties, in Missouri, and crosses the line into Arkansas through Baxter, Marion, Boone, and Carroll counties to the place of beginning. The southern limit of the Ozark dome, however, is not so definitely located as the northern, inasmuch as the Boston mountains on the south either coalesce with the Ozarks, causing the boundary to be carried much farther south, or approach so closely that the two are practically united, depending upon the particular view one may take of this relation. The width of what may properly be called the border area varies from 25 to 40 or 50 miles, depending on the irregularities in the nature of the uplift.

MINING DISTRICTS

The principal mining districts and the areas of ore deposition where mining has not yet been developed to any considerable extent may be enumerated, following the directions as above.

1. In the northeast corner of Indian Territory lead and zinc ores occur in relatively great abundance, with mining development now in the prospecting stage.

2. The Galena-Joplin area, including the extreme southeast corner of Kansas and parts of Newton and Jasper counties, Missouri, with borders reaching into Lawrence and Dade counties and extreme outlying mines in the northwest corner of Barry county and certain parts of Green and Christian counties, in which area lead and zinc ores occur in sufficient abundance to produce some of the richest mines in the world.

3. The central Missouri district, with a crescent-like outline concave southward, one limb reaching to the southwest from Morgan county through southern Benton, Camden, Hickory, and Cedar counties, connecting with the Joplin area through Dade county, the other limb extending to the southeast through Miller, Cole, and Osage counties, connecting with the southeast area through Franklin and Jefferson counties, an area particularly noted for lead ores, but in which there is a large amount of zinc ore.

4. The southeast mining district of Missouri, including Franklin, Jefferson, Washington, Saint Francois, Madison, Iron, Wayne, Reynolds,

and Shannon counties, with a preponderance of lead ore, but producing some zinc ore, a small amount each of copper, nickle, and cobalt ores, and locally large amounts of both red and brown hematite iron ores.

5. The southern Missouri and northern Arkansas district, including practically all the southern counties of Missouri west of Oregon county, and three or four of the northern counties of Arkansas, particularly Baxter, Marion, Boone, and Carroll counties, throughout which area but little mining has been done in the true sense of the term, but which contains "shines" or traces of lead and zinc ores exposed at the surface in almost every county named. It is doubtful if there is a space as great as 25 miles around this border which does not include very good surface prospects for one or another of the ores mentioned.

6. A few mining localities in southern Missouri, which lie outside of what should properly be called the border area, and in the high uplands of the summit of the dome. Thus Aurora and Wentworth, in Lawrence county, and Ashgrove, in western Green county, with other less developed mines in southern Green county and northern Christian county, should properly be looked upon as outside the border area, with perhaps other localities which may become of some importance in the future. Yet the great preponderance of ore deposits as now developed are removed from the summit of the uplift, with the richest ones occupying the outer or lower portions of the border area.

Lithology and Age of Area

VARIETIES OF ROCKS

In lithologic characteristics the rocks included in the Ozark area are of four principal varieties, namely, the Archean crystallines, limestones, sandstones and conglomerates, and the flint or chert.

ARCHEAN CRYSTALLINES

These crystalline rocks are confined to the eastern part of the area considered, being extensively exposed in the southeastern mining district as above outlined. They are granites and porphyries with basic dike-rocks cutting them here and there in many places. The age of the dikes seems to be pre-Cambrian, as they do not extend up into the overlying Cambrian strata. Therefore the period of rock fracturing and volcanic activity with the outflows of lava producing the dike rocks was previous to Cambrian time and perhaps in no way connected with the subsequent movements which produced the principal Ozark uplift. It is probable that a floor of crystalline rocks extends westward under the greater part or all of the Ozark area, being buried to variable depths in different places.

LIMESTONES

Limestone is the most abundant of all rocks found in the area. It is Lower Silurian and Cambrian in age in the eastern part of the territory, and Lower Carboniferous or Mississippian in the western, as is shown by the admirable geological maps published by the Missouri Geological Survey. In general these limestones are very compact and firm; but in some places they are filled with minute openings, particularly in the east where they carry such large quantities of disseminated lead ore; also, they are frequently cut by vertical or semi-vertical fissures carrying ores, particularly around the border areas.

SANDSTONES

The sandstone is moderately abundant in the eastern and southern parts of the territory, the greater part of it being of Lower Silurian or Cambrian age. Although its distribution is comparatively irregular, it is found in great abundance in the southeastern mining area, and also in many parts of southern Missouri and northern Arkansas. In the southwest, in the same geologic formation, it is much less abundant, as is shown by numerous deep wells drilled here and there throughout the southwest mining district. Strangely, a deep well at Neodesha, Kansas, about 55 miles west and a little north of Galena, shows that below a 300-foot bed of Lower Carboniferous limestone and flint, and beginning at about 1,370 feet below the surface, the Silurian sandstone continues almost uninterruptedly for over 1,000 feet, or to the bottom of a well 2,412 feet deep. Throughout this distance an occasional limestone was encountered, but more than three-fourths of the entire 1,000 feet were occupied by sandstone. If reliance can be placed on the records kept by the drillers of the deep wells in the vicinity of Joplin and Carthage, where so much Silurian limestone was found, and I know of no reason for doubting them, it will be seen that the geographic distribution of the Silurian sandstone is unexpectedly irregular.

FLINT OR CHERT

The southwest mining area includes probably the heaviest bodies of flint rock known in the world. Here in different places such bodies are known to be nearly 300 feet thick and have a lateral extent of from 3 to 5 miles. The formations are the Lower Carboniferous or Mississippian limestone, with the flint interbedded in a most irregular manner. Around the borders of heavy flint areas limestone and flint are interbedded with comparative regularity, the alternate layers being sometimes no more than half an inch in thickness. Frequently, however, the flint has manifested a tendency to assume rounded forms, as concretionary masses generally do, so that boulders of many sizes and shapes are common, embedded in the stratified limestone. It is not unusual for a drill or shaft to pass from the surface to a depth of from 50 to 150 feet through limestone, below which flint is found reaching to a much greater depth and bedded with a considerable regularity. Such conditions are noted occasionally about Galena and Joplin and Webb city, but perhaps most markedly so at Wentworth and Aurora, at which places the principal ore deposits occupy the open spaces between successive layers of flint. Around Galena and Joplin the change in horizontal directions from flint to limestone may be gradual or may be very abrupt, being so well marked that the distance of 100 feet will carry one from a solid flint area across to one of correspondingly solid limestone; but such radical changes are exceptional. The fissures in the flint rock about Galena, Joplin, and Webb city are the principal openings which have been filled with lead and zinc ores.

General Character of Ozark Uplift

MONOCLINAL TYPE

The Ozark dome in general is of the monoclinal type of uplifts so common in the great West, although the area is so small it represents the type somewhat in miniature. It seems that the forces producing the uplift acted radially rather than tangentially and resulted in a stretching of the strata rather than a crumpling. On the summit the bedding planes are found to be almost horizontal, while throughout the border areas they are inclined away from the dome center.

STRETCHING OF STRATA

The degree to which the strata were stretched or elongated has not been measured accurately, but indications of it are found on all sides. Winslow has noticed the tendency of the various fissures to contract downward, although he does not particularly refer to the elongation of the surface. Recently, while engaged in a study of the Kansas coalfields in the southeastern part of the state, it was learned that the so-called "horsebacks," so abundant in the coalfields of Cherokee and Crawford counties, are in reality clay-filled seams or fissures, produced by earthquake movements, which trend parallel to the tangent of the

Ozark elliptical area. The brittle coalbeds readily break, and, being dark in color, are most excellent indicators of earth movements. It was found that the stretching of surface lines had resulted in opening these numerous fissures to distances varying from 3 to 30 or 40 feet. It was further observed that such fractures were rarely accompanied by vertical displacement, although one mine near Pittsburg showed a displacement of 8 feet, the downthrow being to the east. The coalbeds to the north and northwest have a much smaller number of "horsebacks" or fissures, the number growing smaller as the distance from the Ozarks increases, until at Osage city and Leavenworth they are entirely unknown, strongly implying that the fissures in Cherokee and Crawford counties were connected in origin with the Ozark uplift.

THE FRACTURES

The fractures appear to be much more numerous around the borders of the uplifted area than in the central part. About Galena and Joplin the flint rocks are so badly shattered that it seems to be impossible to find a fragment 6 inches in diameter free from fissures. The "ribbed" ground is here the prevailing type, so called on account of the great abundance and general parallelism of vertical fissures. To the east at Wentworth and Aurora, nearer the summit of the dome, the heavy flint beds carrying the ores are almost free from fissures and the "ribbed" condition is entirely wanting. A careful study in other parts of the area would probably reveal a similar set of conditions. It is known that fissures are frequently found along the northern border in Hickory, Morgan, and adjacent counties, producing true fissure veins. The same is true to a considerable extent in the southeast about Bonne Terre and Mine La Motte, while northern Arkansas and southern Missouri, although less extensively studied, reveal much the same condition. This is in accord with the general conditions observed elsewhere in areas occupying great monoclinal uplifts, the areas of maximum fracturing and faulting being confined to the borders.

It is probable that the nature of the rocks had a strong influence on the character of the fissures produced by earth movements. The heavy beds of Silurian limestone, with cushions of soft interbedded sandstone, would resist fracture tendencies as well as any rocks known; but when the stress became sufficiently great to produce fracturing the tough and somewhat elastic limestone would yield, producing a small number of relatively large fissures, accompanied by vertical displacement or otherwise, thereby relieving the strain. The opposite extreme is found in the heavy beds of brittle flint about Galena and Joplin. Here the slightest strain would produce fractures in a rock as brittle as glass, already possessing internal tensions of a high degree, so that the required yielding would be along the lines of myriads of small fractures rather than along a few large ones. Large fissure veins and faults of appreciable size would therefore be less frequent than in limestone regions.

But the numerous small fissures would permit weathering agents to pass downward much more generally than in regions of the larger fissures, which, in connection with the interbedded character of the limestone and flint, would cause a much greater dissolving out of the limestones than elsewhere. This in turn would increase the underground openings and bring about to a great degree a falling in of the residual flint masses, resulting in the production of great disturbance, with a maximum opportunity for free circulation of ground waters, one of the essential conditions for extensive ore deposition.

It is a noteworthy fact that the whole Ozark disturbance was unaccompanied by volcanic action of any kind whatever, as far as is now known, save the one little instance in Camden county where a pegmatite dike was discovered by Winslow, with the Mesozoic eruptives of Arkansas being the only other instance known in the whole Mississippi valley of post-Paleozoic volcanic action.

Mineralization of the Rocks

ITS CHARACTER

The mineralization which has taken place has a dual interest, one on account of the character of minerals formed and one on account of the absence of certain other minerals frequently found in areas of great disturbance.

LIST OF MINERALS AND ORES

In the western, northern, and southern parts of the area the ores found are: galena, with its well known alteration products; zinc blende, with its customary alteration products; copper pyrite and secondary mineral, resulting from its weathering; the two iron sulphides, pyrite and marcasite, and their decomposition products; calcite, dolomite, barite, and quartz, with possible traces of a few other minerals not yet observed. In the southeastern district, in addition to those just named, the different iron oxides are found in large quantities, with ores of both cobalt and nickel, and in at least one fissure vein with granite walls at the old Einstein Silver Mines different fumerole minerals, such as quartz, fluorite, topaz, wolframite, and lithia-mica, have been found. In the west quartz is almost entirely unknown, only a few specimens of well crystallized quartz having yet been found at Galena, Joplin, or Webb city. In the vicinity of Wentworth it is more abundant. In the southeastern district quartz is abundantly found in connection with residual masses which constitute the hills and adjacent granite and porphyry areas.

GANGUE MATERIALS

In the Galena-Joplin district about the only gangue associated with the ores that occur in flint rock is a variety of silicious material produced in great abundance filling to different degrees the openings in the rocks and generally carrying more or less galena and blende. This is the cherokite of Jenny, and is variously composed of clay sediments and silicious matter deposited from water solution, sometimes appearing as an incoherent, soft, almost pulverulent mass, but frequently as a hard, fine cement holding together the chert fragments, producing a solid breccia. Between these two extremes are all possible variations.

Calcite is found in large quantities in mines close to limestones, and dolomite likewise is most abundant in such places. Barite is only occasionally found about Galena and Joplin—so rarely, in fact, that the miners have not yet learned to recognize it. Pyrite and marcasite occur in relative abundance; but, compared with the volume of galena and blende, they should be considered as of little importance. Barite gradually increases eastward to the vicinity of Washington and Saint Francois counties, where it becomes sufficiently abundant to constitute an important commercial product.

PECULIAR ABSENCE OF IMPORTANT MINERALS

It is quite important to note the universal absence from the whole area of certain silicate and allied minerals, with the exception of those found in the fissure veins cutting the crystalline rocks of the southeast. The absence of quartz and feldspar and mica and garnet and topaz and fluorite and wolframite and other minerals so frequently found as gangue materials in mining districts where volcanic action, fumerole action, or precipitation from hot solutions have produced the ore deposits, so characterizes the area that its significance becomes very important. It corresponds entirely with the absence of volcanic materials throughout the Ozark area, as already explained. It signifies that metamorphism of all kinds, other than weathering metamorphism, has had no influence. It implies that the earth movements were entirely unaccompanied by heat phenomena of a volcanic nature, and that the movements were so mild regional metamorphism from heat or pressure could not be produced. It further has a strong bearing on the important question of the origin of the ores and causes of mineralization. It practically negatives, it would seem, the idea entertained by some that the lead and zinc ores in general were brought from great depths by hot waters and scattered throughout the rocks adjacent to deep reaching fissures.

CONCLUSIONS

From the foregoing discussions it may be concluded that the mineral area of southern Missouri and adjacent territory owes its existence as such to the peculiar relations existing between the fractures produced in the formation of the Ozark monoclinal uplift and the character of the rocks covering the area. The ore deposits are most abundant where the nature of the fractures permits the greatest freedom in ground water circulation, which is around the borders of the uplift. The character of the rocks likewise has had a great influence on the kind and abundance of fissures produced. In the Joplin district, where flint rock so abounds, its exceeding brittleness caused the production of the greatest number of small fissures and the smallest number of large ones. This, together with the extensive interbedding of limestone and flint, with the limestone largely removed by solution, leaving residual flint masses, has produced most favorable conditions for ore deposition, and hence such exceptionally rich bodies of lead and zinc ores in the district.

The age of the geologic formations concerned is of no consequence, excepting as that may have influenced their ability to withstand strains and their tendency to fracture. Therefore the presence of ore bodies in the Silurian of Madison county, Missouri, implies nothing either for or against the presence of like ore bodies in the Silurian rocks of other localities; nor do the rich lead and zinc mines of Galena and Joplin in the sub-Carboniferous rocks have any bearing on the probable presence of like ore bodies in rocks of the same age in Iowa, Illinois, and other States.

Future mining developments will probably be confined principally to the border areas of the elliptical uplift, a conclusion to be considered by prospectors; yet under most favorable conditions in the character of the rocks valuable ore bodies may occasionally be found far up toward the summit of the dome or equally removed from the border areas in opposite directions, due to exceptional fissuring in such localities.

RÉSUMÉ

The Ozark uplift is elliptical in outline, and occupies the greater part of southern Missouri and small portions of Kansas and Arkansas. The principal mining localities are located around the border of this area in such a manner that some relation between them and the uplift is strongly implied.

The Ozark area is monoclinal in character, with almost horizontal strata on top of the dome and steeper inclinations on the sides. Various degrees of fracturing resulted from the uplift movements, most pronounced, however, around the borders, where the inclination of strata is greatest, and in the flint areas, where the rocks were most brittle. No volcanic phenomena accompanied the uplifting processes, nor was regional metamorphism produced to any extent. The geologic age of the formations concerned is of no special importance in connection with the ore deposits, but the lithologic characters have had a marked influence on the extent to which fracturing has been produced, and therefore on the abundance of ore deposition. The total absence of all kinds of metamorphic minerals associated with the ores, excepting in the fissure veins of the Archean granites, is in harmony with a like absence of volcanic phenomena, and strongly negatives the theory entertained by some that the ores were deposited by hot waters brought up from great depths. Future prospecting should be confined principally to the border areas.

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LOWER DEVONIC ASPECT OF THE LOWER HELDERBERG AND ORISKANY FORMATIONS*

BY CHARLES SCHUCHERT

(*Read before the Society December 28, 1899*)

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INTRODUCTION

Why is it that nearly all leading American stratigraphers as well as the authors of the principal American geological text-books—Dana,* Le Conte,† Williams,‡ and Scott §—refer the Lower Helderberg to the Siluric system? This question gains peculiar force when another fact is pointed out, namely, that nearly all European stratigraphers who have investigated the systemic position of the Lower Helderberg, and Geikie, || Kayser, ¶ and Frech, ** in their respective text-books, unhesitatingly place the same formation in the Devonic, as lowest Lower Devonic. This is not merely a question of drawing the line between two geological eras, a little higher or a little lower in the time scale, but it involves taxonomic principles and stages in faunal or evolutional progression.

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* James D. Dana: Manual of Geology, 4th ed., New York, 1896, pp. 535, 569, 576.

† Joseph Le Conte: Elements of Geology, New York, 1878, p. 282. The Oriskany is here also included in the Siluric. In the edition of 1895 the Siluric terminates with the Lower Helderberg (see p. 296).

‡ Henry Shaler Williams: Geological Biology, New York, 1895, pp. 33, 52.

§ William Scott: An Introduction to Geology, New York, 1897, pp. 385, 394.

|| Sir Archibald Geikie: Text-book of Geology, London, 1893, p. 790.

¶ E. Kayser: Text-book of Comparative Geology, translated by Philip Lake, London, 1893, p. 111.

** Fritz Frech: Lethæa geognostica, 1 Theil, 2 Band, Stuttgart, 1897, p. 207.

One of the chief reasons for these varying views lies in the fact that the lower limit of the Devonic of England has never been defined, and its lowest well marked fauna is apparently not older than the Oriskany. Again, Barrande included his étages F, G, and H, together with the Lower and Upper Helderberg, in the Siluric. These are now regarded by most continental paleontologists, however, as of Lower and Middle Devonic age. Americans have not apparently paid much attention to the recent developments in the Lower Devonic of the Rhineland. Geikie writes that—

> "It is rather from the sections and fossil collections of central Europe than from those of England that the stratigraphy and paleontology of the Devonian system are to be determined."

Murchison, in reviewing his work of 1842 in the Rhenish area, twelve years later, says:

> "I have been convinced, through the paleontological labors of Ferdinand Roemer and the brothers Sandberger, that the types of that lower Rhenish subdivision are distinct from the Upper Silurian, and in harmony with the lowest Devonian group of other countries."

The geographically restricted condition of the Lower Helderberg and the completeness with which its fauna was described by Hall, in 1859, have left Americans little opportunity to examine its systemic position. The influence of that great nestor of American geologists has so established the position of the Lower Helderberg, that writers of text-books seem unwilling to set aside his conclusions. When Clarke published his paper on "The Hercynian question" the present writer was assistant to Professor Hall. At that time, Clarke proved the unmistakable Devonian aspect of the Lower Helderberg fauna, and Hall is not known to have objected to this presentation. Walcott,* in reviewing Clarke's paper, states in conclusion that—

> "This suggestion [Lower Helderberg = Lower Devonian], comes to me with peculiar force at the present time, and, if the Silurian system was to be reclassified today, I should favor the following scheme: Lower division, Canadian, Calciferous, and Chazy; middle division, Trenton and Hudson, and upper division, Niagara and Salina. The summit of the Silurian would be drawn at the Waterlime formation, and the Lower Helderberg would be considered, with the Oriskany sandstone, as lowest Devonian. This, to my mind, is the more natural classification, and divides the Paleozoic into four subequal groups—Cambrian, Silurian, Devonian, and Carboniferous."

It may be well to state here that most system boundaries are established in regions where some physical event has made a break in the continuity of faunal evolution. In establishing such a boundary elsewhere one may assume the physical event to have been general or local in character. In the first case the system boundary is marked by an abrupt change in life; in the second there will be a gradual faunal transition, necessitating the somewhat arbitrary placing of the boundary. The writer holds that present knowledge is more in harmony with the view that physical events are local and faunas transitional. However, in carrying out this view in correlating widely separated areas, one will incur fewer difficulties by conforming as far as possible to the limitations of the systems as originally defined by their makers.

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*Amer. Jour. Sci., vol. xxxix, 1890, p. 156.

The upper limits of the Silurian have been established by Murchison, and strata younger than the "Tilestones" and "Downton Castle sandstone" can not well be added to this system unless such have a fauna whose facies is Silurian. Professor Williams* writes:

> "Systems were originally groups of successive rock formations; their limitation was therefore determined, in the first place, by the extent of the rocks in the particular region where they were first defined. Hence the series of formations constituting an original system is in each case a standard of reference, and its general application is accomplished by determining its equivalent formations in other regions. . . .
>
> "It is all-important to know what formations make up these standard systems; for only as other rocks contain the same faunas or floras can they be identified as of equivalent age and therefore as belonging to the same system. The real time indicators are, therefore, the fossils."

Has the Lower Helderberg a Siluric facies, when but 11 species, or about 2 per cent, of its fauna of 459 forms are derived from the Siluric? The generic differences are even more marked, and Clarke has well said that—

> "The upper limit of the typical Silurian section was clearly defined, and time has shown that this limit was not only one of a geological series, but the dead-line of a large number of organic types."

As to the relation of the Oriskany to the Lower Helderberg, Hall,† in 1859, wrote as follows:

> "The great changes in the physical conditions supervening at the close of the preceding group [Lower Helderberg] indicate an influence which would affect in an equal manner the fauna of the succeeding one, and we find accordingly few species passing from the Lower Helderberg group to the Oriskany sandstone. The changes, however, are mainly of a specific character; no new genera being introduced.
>
> . . . .
>
> "It is not possible, therefore, to point out any changes in the fauna of this period sufficient to indicate the commencement of a new system, and its relations with

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*Geological Biology, 1895, p. 31.

† Paleontology of New York, vol. iii, 1859, pp. 401–402.

the formations below are as intimate as with those above; while in the Northern and Middle States, the Oriskany sandstone bears in its fauna a closer relation to the lower than to the overlying formations."*

It will be shown that the Lower Helderberg has its equivalent, faunally, in Barrande's étage F_2, as found at Koniepruss, in Bohemia, and that, in the Rhine section, German geologists have for this formation a fixed place in the Lower Devonic.

In his "Synopsis of American fossil Brachiopoda," published three years ago by the U. S. Geological Survey,† the writer included all Lower Helderberg and Oriskany species in "Table VI, Devonian Brachiopoda," as "Eodevonian." Apparently no one has noticed this radical departure from accepted American standards; at least, no one has pointed it out or given reasons why these forms are not of Devonic age.

SILURIAN OF MURCHISON ‡

APPLICATION OF THE TERM BY GEOLOGISTS

In 1835, the term Silurian was first applied by Murchison to a series of formations well developed in Shropshire, England, a "region once inhabited by the British tribe of Silures;" hence the name.

> "From the base of the Old Red sandstone, he was able to trace his Silurian types of fossils into successively lower zones of the old 'Grauwacke.' It was eventually found that similar fossils characterized the older sedimentary rocks all over the world, and that the general order of succession worked out by Murchison could everywhere be recognized. Hence the term Silurian came to be generally employed to designate the rocks containing the first great fauna of the Geological Record."

At first the Silurian not only included what is now known as Lower Silurian, or Ordovicic, or Champlainic, and Upper Silurian, or Siluric, but also much of the Cambrian of Sedgwick. "The controversy regarding the respective limits of the Cambrian and Silurian formations survived the lifetime of the two great antagonists." §

The present work, however, has no bearing on the lower limit of Murchison's Silurian, but aims to determine what constituted the upper limit of his "Upper Silurian" and the lower limit of his "Devonian."

Regarding the Upper Silurian, Murchison, in 1854, in his "Siluria," wrote as follows:

> "When, on the contrary, we follow the same deposits from North and South Wales to the exemplar tracts of Herefordshire and Shropshire, where the Upper

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* For further remarks see p. 291.

† Bulletin no. 87.

‡ See Geikie's Text-book of Geology, 3d ed., 1893, p. 737.

§ Geikie, p. 737.

> Silurian rocks were first classified and described, we find them diversified by interpolated courses of limestone; much calcareous matter being also disseminated, both in nodules and in flagstones.
>
> "With additions like these to the richness and variety of the subsoil, which are so welcome to the proprietor and farmer, the geologist usually discovers a much greater abundance of fossil animal remains than in the same strata of the sterile western tracts. By observing the order of superposition, and by tracing the divisionary limestones, he reads off the order of the strata, and chronicles with precision the succession of their respective fossils.
>
> "In this way the Upper Silurian rocks are seen to consist, as a whole, of the two formations to which I assigned the names of Wenlock and Ludlow, each of these being subdivided in the manner expressed in this woodcut."*

Murchison then describes the various horizons, and names the diagnostic fossils for the Upper Silurian. Regarding the highest beds of the Ludlow, he states that—

> "The upper portion of the Ludlow formation, or capping of the bone bed is composed of light colored, thin bedded, slightly micaceous sandstones, in which quarries are opened out near Downton castle on the Teme.† The uppermost layers of the whole system, and which form a transition into the Old Red sandstone, consist of tilestones and sandstones, occasionally reddish, in which, besides other fossils found in the Ludlow rock, the Lingula cornea, with crustaceans [Leptocheles], and defenses of fishes, often occur.
>
> "Being compelled in my researches to draw a line of demarkation between the upper part of the Ludlow formation and the bottom of the overlying Old Red sandstone, I formerly included the tilestones in the latter; particularly as in most parts of the region they decompose into a red soil, and thus they afford a clear physical line of demarkation between them and the inferior rocks, which facilitated the construction of the geological map.
>
> "Even then, however, the fossils which were figured as characteristic of such tilestones exhibited little else, as I showed, than species common to the Ludlow rock itself. This zoological fact, and subsequent researches in other parts of England, above all those of Professor Sedgwick in Westmoreland, where the Upper Ludlow strata are much developed, have, for eleven years, led me to classify these tilestones with the Silurian rocks, of which they form the natural summit. [The fossils are listed and figured on plate xxxiv.] All of these are the most common fossils of the Upper Ludlow rock; although a few of them descend as low as the Caradoc sandstone." ‡

With the exception of the fishes, the fauna included in these tilestones, and listed by Murchison, is in harmony with the American Upper Silurian. It does not suggest anything higher than the Niagara group. On this point, Kayser, who has given much attention to the stratigraphy and paleontology of the Lower Devonic, writes as follows: *

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*Siluria (pp. 101–102). The legend to this woodcut forms the first column of the correlation table beyond.

†The Downton Castle stone, Silurian system, p. 197.

‡Ibid., pp. 138, 139.

> "Paleontologically the Ludlow rocks, on the whole, are commonly very closely related to the Wenlock; most of the mollusks, many of the trilobites and other fossils are common to the two formations, and only a few forms, such as *Cardiola interrupta* and *Pentamerus Knighti*, are, if not entirely limited to the upper beds, at least chiefly found in them. A special peculiarity of the Ludlow is the appearance, even in the lowest beds, of numerous Eurypterids (especially *Eurypterus* and *Pterygotus*—forms which become very abundant in the Old Red sandstone)—and the peculiar Cephaspidæ (*Cephalaspis, Scaphaspis, Pteraspis*, etcetera), the oldest of British fishes."

The Upper Silurian of England, as given by Geikie in 1893, is practically that of Murchison in 1854, with the exception of the Lower and Upper Llandovery and Tarannon shales. These had been referred by the former to his Lower Silurian, but by the latter are regarded as the base of the Upper Silurian. The upper limits of the Upper Silurian are defined by Geikie as follows:

> "Above the Upper Ludlow shales and mudstones lies a group of fine yellow, red, and gray micaceous sandstones from 80 to 100 feet thick, which have long been quarried at Downton castle, Herefordshire. At Ledbury these sandstones are surmounted by a group of red, purple, and gray marls, shales, and thin sandstones, having a united thickness of nearly 300 feet. Originally the whole of these flaggy upper parts of the Ludlow group were called 'tilestones' by Murchison, and, being often red in color, were included by him as the base of the Old Red Sandstone, into which they gradually and conformably ascend. They point to a gradual change of physical conditions, which took place at the close of the Silurian period in the west of England and brought in the peculiar deposits of the Old Red Sandstone. There is every reason to believe that for a long time the marine sedimentation of Upper Silurian type continued to prevail in some areas, while the probably lacustrine type of the Old Red Sandstone had already been established in others, and that by the breaking down or submergence of the barriers between these different areas, marine and lacustrine conditions alternated in the same region. The tilestones are the records of this curious transitional time. . . .
>
> "The evidence from fossils is equally explicit. Up to the top of the Ludlow rocks, the abundant Silurian fauna continues in hardly diminished numbers. But as soon as the red strata begin the organic remains rapidly die out, until at last only the fish and the large eurypterid crustaceans continue to occur." †

DOWNTONIAN

In a very recent detailed work, "Silurian Rocks of Britain," Messrs B. N. Peach and John Horne ‡ write of the uppermost Silurian rocks of Great Britain as follows:

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* Text-book of Comp. Geology, 1893, p. 65.

† Geikie, pp. 760–762.

‡ Memoirs Geol. Survey of United Kingdom, 1899, pp. 67–69, 80, 568.

> "Downtonian has hitherto been regarded as of Lower Old Red Sandstone age, owing to the prevalence of red and yellow sandstones and shales which are the prominent feature of that formation. The recent discovery by the Geological Survey, in shales and mudstones intercalated in these sandstones, of a marine fauna which in some respects is identical with that of the underlying Ludlow Rocks has led to a revision of the classification hitherto adopted. These passage beds are now viewed as forming the highest subdivision of the Upper Siluriãn rocks."

The following is a tabulation of the Downtonian, in descending order, with an enumeration of the essential fossils. The thickness of the series is from 700–2,700 feet.

4. Chocolate-colored sandstones.
3. Conglomerate with quartzite pebbles derived from the Highlands.
2. Green and red mudstones with bands of graywacke and brown flaggy carbonaceous shales with fishes and eurypterids. Plants: *Pachytheca*, *Parka*. Animals: *Beyrichia*, *Ceratiocaris*, *Eurypterus*, *Pterygotus*, *Slimonia*, *Stylonurus*, *Glauconome*, *Spirorbis*. Fishes: *Thelodus* and four other restricted genera.
1. Red and yellow sandstones and mudstones.

The fossils mentioned above are Siluric in age and remind rather of the Tentaculite and Waterlime than of the Lower Helderberg. Messrs Peach and Horne add:

> "In view of the paleontological and to some extent also of the physical evidence regarding the passage-beds that overlie the Ludlow rocks, there seems ground for maintaining that they have greater affinities with the Silurian system than with the Old Red Sandstone. They may be looked upon as stratigraphical equivalents of the Tilestones, Downton sandstones, and Ledbury shales, which in Herefordshire, overlie the Upper Ludlow rocks, and have been classified as forming the highest subdivision of the Upper Silurian rocks."*

AMERICAN EQUIVALENTS

In North America the Siluric faunas are also abundant in species, and, with a gradual change toward higher types, continue from the Anticosti formation through the Guelph, when red shales, salt and gypsum bearing, begin and bear witness to an almost total extermination of animal existence throughout the Onondaga (= Cayugan) formation. Here, as in England, eurypterid crustaceans are the prevailing fossils, but in America fishes are generally absent.

In eastern New York, above the "Waterlime" a small but normal marine fauna again makes its appearance in the Tentaculite (= Manlius) limestone. It consists of 26 species, and 4 of these, are known to occur in some higher member of the Lower Helderberg.* These figures show that the Tentaculite limestone is transitional to the Lower Helderberg, yet its fauna does not forcibly bring to mind that of the Lower Pentamerus immediately above.

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*Silurian Rocks of Great Britain, p. 568.

Fauna of the Tentaculite Limestone of New York

† *Homocrinus scoparius* Hall.
Monotrypa (?) *spinulosa* (Hall and Simpson).
† *Stropheodonta varistriata* (Conrad).
‡ *Orthothetes hydraulicus* (Whitfield). 27859.§
Spirifer vanuxemi Hall. 4692, 9112, 26043, 10549.
Tellinomya nucleiformis Hall.
Goniophora dubia (Hall). 4693.
Illionia sinuata (Hall).
Aviculopecten (?) *obscura* (Hall).
Holopea subconica Hall.
Holopea antiqua (Vanuxem). 10625.
Holopea pervetusta (Conrad).
? † *Holopea* (?) *elongata* Hall.
Murchisonia extenuata Hall.
Murchisonia minuta Hall.
? † *Euomphalus sinuatus* Hall.
Tentaculites gyracanthus (Eaton). 5001, 10549, 17514, 9120.
† *Spirorbis laxus* Hall.
Oncoceras ovoides Hall.
Cyrtoceras subrectum Hall. 10628, 4682.
Leperditia alta (Conrad). 4699, 9115, 17515, 25853.
Leperditia parvula Hall. 10551, 10552.
Beyrichia parasitica (Hall).
Beyrichia clarkii Jones.
Beyrichia trisulcata Hall.
† *Klœdenia notata* (Hall). 10551, 10552.

American paleontologists acquainted with this fauna and that of the typical Lower Helderberg will at once see that it is not the Tentaculite fauna which gave the Lower Helderberg sea its multitudinous forms of life. It was rather that of the Niagara epoch, which continued to live and undergo modification in some unknown area while the Salina shales and Waterlimes were deposited. This fauna, transitional between the Niagara and the Lower Helderberg, may be that of the Guelph, Meniscus, and the higher Siluric dolomites of Ontario and the central United States. In any event, the Tentaculite fauna has a decided Siluric facies. It seems that the most natural line (faunally) for the separation of the Siluric and the Lower Helderberg lies at the top of the Tentaculite limestone, and that the fauna of the Lower Pentamerus is the earliest stage in the Devonic cycle of marine life.

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* In Ohio a similar fauna is present in the "Hydraulic limestone of the Lower Helderberg" (Geol. Survey of Ohio, vol. vii, 1893, pp. 410–418). The following are the species:

Orthothetes hydraulicus (Whitfield).
Spirifer vanuxemi Hall.
* *Meristella lævis* (Vanuxem).
* *Meristella bella* Hall.
Nucleospira rotundata Whitfield.
* *Rhynchospira formosa* Hall.
Rhynchonella hydraulica Whitfield.
Pentamerus pesovis Whitfield.
* *Pterinea aviculoidea* Hall.
Goniophora dubia Hall.
Eurypterus eriensis Whitfield.
Leperditia alta Conrad.
Leperditia angulifera Whitfield.

† Also in higher Lower Helderberg.
‡ Also in the Onondaga (= Cayugan).
§ Register number of the specimens in the U. S. National Museum.

Submergence and transgression begins with the Tentaculite, but in the Lower Helderberg sea are more decided than during any period of the Siluric. In eastern Pennsylvania the Lower Helderberg reposes on Clinton strata; in southern Illinois and adjoining Missouri, on Ordovicic strata, and in Gaspé on the Quebec. This evidence, therefore, shows a marked transgression over eroded land areas in widely separated localities. The Oriskany sea continues the Lower Helderberg submergence and transgression, since in New York, from east to west, it gradually comes to rest on the various members of the Lower Helderberg and finally upon the Waterlime (= Rondout limestone).

In 1882, Hall * also pointed out that "while the trend [line of greatest deposition] of the limestones of the Niagara and the two succeeding calcareous groups has a general east and west direction, the Lower Helderberg has a northeast and southwest trend."

It may also be well to state here that the Lower Helderberg is nearly everywhere followed by some member of the Oriskany. This is true for New York as well as practically throughout the length of the Appalachians, Illinois, Tennessee, and Gaspé. The Oriskany is absent in Indian Territory, and is present without the Lower Helderberg in the region of Cayuga, Ontario.

Mr Bailey Willis, of the United States Geological Survey, who has made a special study of the middle and southern Appalachian mountains, will publish the following in the third volume of the Geological Survey of Maryland:

> "The student of physical changes finds no important episode of mountain growth or continental development to define the close of the Silurian period and the beginning of the Devonian. The record describes Appalachia as a monotonous lowland, now rising a little higher, now not so high, above the fluctuating coast of marsh and tideflat. . . . Before the Oriskany in the Lower Helderberg epoch it had assumed these aspects which are considered to characterize the Devonian period."

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* Contribution to Geol. Hist. Amer. Cont. Presidential address, A. A. A. S., Montreal, 1857. Republished, Salem, 1882, pp. 48, 49, 68.

TABLE OF ENGLISH AND AMERICAN SILURIC EQUIVALENTS

	Wales and Shropshire. Upper Silurian, Murchison, 1854. (Siluria, 1854, page 102.)	Wales and Shropshire. Upper Silurian, Geikie, 1893. (Text-book of Geology, page 753.)		Wales. Upper Silurian, Kayser, 1893. (Text-book of Comparative Geology, page 64.)		North America. Siluric or Ontaric equivalents, Schuchert.		
Devonic.	Old Red Sandstone.	Base of Old Red Sandstone.		Old Red Sandstone.	Devonic	Coeymans or "Lower Pentamerus" limestone.		
Siluric or Ontaric.	Upper Silurian. Upper Ludlow, including Tilestones. Middle Ludlow or Aymestry limestone. Lower Ludlow.	Tilestones, 300 feet. Downton Castle sandstone, 90 feet. Ledbury shales, 270 feet. Upper Ludlow rock, 140 feet. Aymestry limestone, up to 40 feet. Lower Ludlow rock, 350 to 700 feet.	Ludlow group.	Ludlow or Clunian (Downtonian). Ledbury shales. } Passage beds or Tilestones. Downton sandstone. } Passage beds or Tilestones. Upper Ludlow beds, including the bone bed. Aymestry limestone.	Neontaric or Cayugan.	Manlius, or "Tentaculite limestone," 50 to probably 300 feet or more. Rondout, or "Waterlime." Salina beds. Shales and marlites (Salina group), with Waterlime zones generally near the top ("Waterlime group").	300 to 1,600 feet.	A typical marine fauna is generally absent.
	Wenlock limestone. Wenlock shale. Wenlock shale, with lower, or Woolhope limestone.	Wenlock, or Dudley limestone, 300 feet. Wenlock shale, up to 2,300 feet. Woolhope, or Barr, limestone and shale, 150 feet.	Wenlock group.	Wenlock or Salopian. Lower Ludlow beds. Wenlock limestone. Wenlock shale and Woolhope limestone.	Mesontaric or Niagaran.	Guelph limestone, 160 feet (probably in part is the marine facies of the Salina shales). Waldron shale, 4 to 20 feet. Lockport limestone, 4 to 300 feet (includes the "Coralline limestone") Rochester shale, 80 feet. Clinton beds, 50 to 1,000 feet.		Anticosti divisions, 1 to 4, 1,350 feet.
	Lower Silurian. Pentamerus limestone on the summit of the Caradoc sandstone.	Tarannon shales, 1,000 to 1,500 feet. Upper Llandovery rocks and May Hill sandstone, 800 feet. Lower Llandovery rocks, 600 to 1,500 feet.	Llandovery group.	Llandovery or Valentian. Tarannon shales. May Hill sandstone = Upper Llandovery. Lower Llandovery beds.	Paleontaric or Oswegan.	Medina sandstone. Oneida conglomerate (includes Shawangunk).	300 to 1,800 feet.	
		Lower Silurian or Ordovician.			Champlainic.	A marked faunal hiatus occurs here. Cincinnatian (Richmond beds).		

From Lower Helderberg time deposition is again continuous, and the chain of life in the American Appalachian and Mississippian seas is almost unbroken to the close of the Paleozoic. There is probably no land area preserving so continuous and undisturbed a sequence of Paleozoic deposits as that of eastern North America. From Lower Cambric time to the close of the Permic, the only marked hiatus exists between the Ordovicic and Siluric, and this may have been caused by the elevation of the Taconic mountains. However, beyond this area, in the gulf of Saint Lawrence, even this gap will probably be largely bridged over by the fossils preserved in the Ordovicic and Siluric strata of Anticosti island. These, as yet, have not been sufficiently studied; but it is clear from the work of Billings that the Ordovicic and Siluric fossils of Anticosti have more in common than these systems have elsewhere in America.

The table on page 251 shows the equivalents of the English Upper Silurian as understood by Murchison in 1854, and by Geikie and Kayser in 1893, with the American homotaxial equivalents.*

CONCLUSIONS

With the foregoing presentation, it is clear that the upper faunal limits of the original Upper Silurian have been and still are vague, because the normal marine fauna gradually succumbed to local conditions associated with the production of red sediments.

> "As a series of rocks the upper limit of the typical Silurian section was clearly defined, and time has shown that this limit was not only one of a geological series, but the dead-line of a large number of organic types." †

Lower Devonic‡

DEVONIAN OF SEDGWICK AND MURCHISON

The following résumé by Murchison § gives a clear history of the progress regarding the Devonian rocks in the type area:

> "*Devonian rocks* (*the equivalents of the Old Red*) *in Devon and Cornwall.*—The crystalline and slaty condition of most of the stratified deposits in Devon and Cornwall, and their association with granitic and eruptive rocks and much metalliferous mat-

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* The divisions and terminology here adopted are those of Clarke and Schuchert. Science, vol. x, December 15, 1899, pp. 874–878.

† Clarke: Review of "Die Fauna des Unteren Devon am Ostabhange des Ural." Am. Geol., vol. xiv, 1894, p. 121.

‡ The results of this section are arranged in tabular form beyond.

§ Siluria, London, 1854, pp. 257–258. For an encyclopedic paper on the history of the Devonian to 1867, see Quart. Jour. Geol. Soc. London, vol. xxiii, p. 568, by Robert Etheridge; also "The Geology of England and Wales," by Horace B. Woodward, London, 1887.

ter, might well induce the earlier geologists to class them as among the very oldest deposits of the British Isles. In truth, the southwestern extremity of England presented apparently no regular sedimentary succession, by which its gray, slaty schists, marble limestones, and silicious sandstones could be connected with any one of the British deposits the age of which was well ascertained. The establishment of the Silurian system, and the proofs it afforded of the entire separation of its fossils from those of the Carboniferous era, was the first step which led to a right understanding of the age of these deposits. The next was the proof obtained by Professor Sedgwick and myself, that the 'culm measures' of Devon were truly of the age of the Carboniferous limestone, and that they graduated downwards into some of the slaty rocks of this region. Hence, in the sequel it became manifest, that the rocks, now under consideration, were the immediate and natural precursors of the coal era, and stood therefore in the place of the Old Red Sandstone of other regions. The highly important deduction, however, of Mr Lonsdale, that the fossils of the South Devon limestones, as collected by Austen and others, really exhibited a character intermediate between those of the Silurian system and of the Carboniferous limestone, was the most cogent reason which induced Professor Sedgwick and myself (after identifying North and South Devon) to propose the term Devonian.* The inference that the stratified rocks of Devonshire and Cornwall, though of such varied composition, are really the equivalents of the Old Red Sandstone in the regions alluded to has since, indeed, been amply supported and extended by the researches of Sir Henry De la Beche, Professor Phillips, and many other good geologists.†

"The most instructive of the sections published by my colleague and myself to illustrate the general structure of Devonshire, is that of which the diagram in page 256 is a compiled reduction. [*a*, Lowest Devonian beds of schists and red micaceous sandstone of North Foreland; *b*, red sandstone and conglomerate of Linton; *c*, gray schists and Stringocephalus limestone of Ilfracombe, etcetera. Beds *a* and *b* are compared with the lower shelly graywacke of the Rhine (Coblenz, etcetera).] It is a section across North Devon from the Foreland on the British channel, to the granitic ridge of Dartmoor on the south, and exhibits a copious succession of the Devonian rocks between Linton and Ilfracombe on the north, and Barnstable on the south, the whole dipping under strata of the Carboniferous age, on the opposite side of a wide trough of which, or on the north flank of Dartmoor, the Upper Devonian strata again rise to the surface.

"North Devon has thus been selected as affording, on the whole, the best type of succession of the rocks to which the name Devonian was applied; because it offers a clear ascending section through several thousand feet of varied strata, until we reach other overlying rocks, which are undeniably the bottom beds of the true Carboniferous group."

Murchison and many later geologists, including Geikie, hold that the Old Red sandstone and the Devonian of North and South Devon are equivalents. As a name, therefore, Old Red sandstone has priority over that of Devonian, but since in the latter area marine fossils occur, enabling similar horizons to be identified elsewhere, this systemic name has supplanted that of the Old Red sandstone, and is now generally recognized the world over. In regard to the latter formation, Geikie* writes as follows:

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*See Reports of Brit. Assoc. for the Advancement of Science, 1836, Bristol meeting. Sedgwick and Murchison, Trans. Geol. Soc. London, vol. v, p. 633, and Phil. Mag., vol. xi, p. 311. Lonsdale, Trans. Geol. Soc. London, vol. v, p. 721.

†See Report on the Geology of Cornwall, Devon, and W. Somerset, by De la Beche, 1839, and the Palæozoic fossils of the same region, by Professor Phillips, 1841.

> "In Wales and the adjoining counties of England, where the typical development of the Silurian system was worked out by Murchison, the abundant Silurian marine fauna disappears in the red rocks that overlie the Ludlow group. From that horizon upwards in the geological series, we have to pass through some 10,000 feet or more of barren red sandstones and marls, until we again encounter a copious marine fauna in the Carboniferous limestone. It is evident that between the disappearance of the Silurian and the arrival of the Carboniferous fauna, very great geographical changes occurred over the site of Wales and the west of England. For a prolonged period, the sea must have been excluded, or at least must have been rendered unfit for the existence and development of marine life, over the area in question. The striking contrast in general facies between the organisms in the Silurian and those in the Carboniferous system, proves how long the interval between them must have been.
>
> "At present the general belief among geologists is that, while in the west and north of Europe the Silurian sea-bed was upraised into land in such a way as to inclose large inland basins, in the center and southwest the geographical changes did not suffice to exclude the sea, which continued to cover that region more or less completely. In the isolated basins of the west and north, a peculiar type of deposits, termed the Old Red Sandstone, is believed to have accumulated, while in the shallow seas to the south and east, a series of marine sediments and limestones was formed, to which the name of Devonian has been given. It is thus supposed that the Old Red Sandstone and Devonian rocks represent different geographical areas, with different phases of sedimentation and of life, during the long lapse of time between the Silurian and Carboniferous periods. . . .
>
> "That the Old Red Sandstone of Britain does represent the prolonged interval between Silurian and Carboniferous time can be demonstrated by innumerable sections, where the lowest strata of the system are found graduating downward into the top of the Ludlow group, and where its highest beds are seen to pass up into the base of the Carboniferous system. . . . It is quite possible, therefore, that the lower portions of what has been termed the Devonian series may, in certain regions, to some extent represent what are elsewhere recognized as undoubtedly Ludlow or even perhaps Wenlock rocks.†
>
> "Yet even at the best the Devonian rocks of this classical region, though they served as the type formations of the same geological age elsewhere, are much less clearly and fully developed than those of the Rhine country and other parts of the continent. It is rather from the sections and fossil collections of central Europe than from those of England that the stratigraphy and paleontology of the Devonian system are to be determined."

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* Text-book of Geology, 3d ed., 1893, pp. 777-778, 783.

† See *ante*, Peach and Horne.

Frech[*] gives the following scheme showing the relation of the non-marine Old Red sandstone to the normal marine Devonian:

"*Non-marine development.*	*Marine development.*
Upper Old Red sandstone =	Lower Carboniferous, in part. Upper Devonian.
Land condition and transgression =	Middle Devonian.

[There is no middle Old Red sandstone. The interval is indicated by a great discordance.]

Lower Old Red sandstone =	Lower Devonian. Upper Silurian, in part."

These citations make it clear that in Wales and England a series of red marls and sandstones set in near the close of the Siluric, and continued without change through the Devonic into the Lower Carbonic period. During the deposition of 10,000 feet of Old Red sandstone strata no normal marine fauna occurs, and the best criterion for time sequence is therefore absent.

In Devon and Cornwall there is another series of Devonian rocks, and as these bear normal marine faunas they represent the type area for the Devonic system. However, it is only in recent years that the small English Lower Devonic faunas have become somewhat known. For this reason it was long ago recognized that the Devonic system could be studied to better advantage in the Rhineland.

> " The Devonian system was founded upon one of the most unfavorable and incomplete developments of that series of rocks and faunas known in any part of the globe; a more precise scope was given to it by the work of its founders, Murchison and Sedgwick, in the Rhineland, but even there no determination of its lower limit was made. This admitted hiatus in the typical succession of Devonian to Silurian is the parent of the prolific discussions over 'post-Silurian' and 'Hercynian' faunas."[†]

Of the Devonic of Rhineland, Kayser,[‡] one of the leading students of the German Devonic, writes as follows:

> Murchison and Sedgwick "first broke ground on the continent in the Rhenish Schiefergebirge and their westerly extension, the Ardennes, the largest and best developed Devonian area of western Europe, which even up to the present day continues to add more to our knowledge of the Devonian than any other [European] area.
>
> "The famous essay of the two English observers devoted to the Rhenish mountains appeared in 1842,[§] and its value was enhanced by the paleontological appendix

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[*] Lethæa geognostica, 1 Theil, 2 Band, 1897, p. 118.

[†] Clarke, in a review of the work cited, American Geologist, vol. xiv, 1894, p. 119.

[‡] Text-book of Comparative Geology, by E. Kayser, translated by Philip Lake, London, 1893, pp. 89–91.

[§] Trans. Geol Soc., 2d ser., vol. vi, p. 222.

contributed by d'Archiac and de Verneuil. In this classical work, a part of the Taunus and Hunsrück was considered as Cambrian; the chief mass of the Schiefergebirge as Silurian; a smaller part, including the Eifel Limestone formation, as Devonian; . . . but the classification of the older beds has needed considerable alteration. The merit of undertaking this necessary revision is due to the 'Rheinischen Uebergangs-gebirges' of Ferd. Roemer, appearing in 1844, in which the author shows that the chief mass of the Schiefergebirge must, according to its fossils, be correlated not with the English Silurian, but with the Devonian.

"The extent of the Devonian in the Rhenish Schiefergebirge, the accuracy of the observations made upon it, the completeness and variety of the series, and its richness in fossils," make it the most important area for this system. "This mountain region, which in general has the form of a plateau, stretches from the Eder and Diemel to beyond the Meuse," and consists of "strongly compressed beds," with a "system of reversed folds. . . . All these folds consist of Devonian rocks, altogether probably at least 20,000 feet thick.

"Within the Devonian rocks themselves no unconformity has yet been found, and the whole succession seems to have been deposited without any important check, and passes up without break into the overlying Culm."

The errors made by Murchison and Sedgwick in the Rhenish area were admitted by the former after seeing Roemer's work above mentioned, and in his famous book "Siluria" (1854) he writes as follows:

"The clear general views of that Nestor of geologists, D'Omalius d'Halloy, the remarkable work and map of M Dumont, as well as the previous labors of Prussian geologists, including the maps of Leopold von Buch, Hoffman, von Dechen, and Öynhausen, unquestionably led the way in the succession of efforts, through which our present knowledge has been obtained. After the publication of the above works, Professor Sedgwick and myself endeavored to show (1839) that, like Devonshire and Cornwall, the Rhenish provinces contained a great mass of those strata, intermediate between the Silurian and Carboniferous deposits, which we had called Devonian; the equivalent, in our belief, of the Old Red Sandstone of Scotland and Herefordshire. Our contemporaries have admitted that, in our excursion of one long summer in Germany, we succeeded in proving the existence of such an intermediate series both in Prussia and Belgium, and also in showing how, on the right bank of the Rhine, the uppermost 'grauwacke' was divisible into Lower Carboniferous and Upper Devonian rocks. Misled, however, by an erroneous interpretation of some of the fossils (for at that time the Lower Devonian forms had been little developed), we adopted the belief, that the inferior 'fossiliferous grauwacke,' or that which has since been called the 'Spiriferen Sandstein' of the Rhine, was an equivalent of the Upper Silurian. I have been convinced, through the paleontological labors of Ferdinand Roemer and the brothers Sandberger, that the types of that lower Rhenish subdivision are distinct from the Upper Silurian, and in harmony with the lowest Devonian group of other countries. And for some years I have been aware that, whilst our sections representing the succession of the mineral masses were correct, the interpretation or synonymy to be attached to the lower division was erroneous. . . .

"It is, however, satisfactory to have ascertained in a recent visit to my old ground, that all the knowledge acquired in the fourteen years which have elapsed since our survey was made, has but led to a much more complete identification of the Rhenish provinces with Devonshire, than that which was proposed by my colleague and myself. In short, it now appears that not some only, as we thought, but all the paleozoic strata of Devon have their equivalents on the banks of the Rhine. So, that, starting from the North Foreland of the British channel, and ascending into the heart of the culm fields, . . . the geologist has before him the successive representatives of the Rhenish deposits.

"Those persons who may refer back to the sixth volume of the Geological Transactions of London, will, therefore, understand that all the Rhenish ground which is described or colored in the map and sections as Upper Silurian, is now embodied in the Devonian rocks; whilst to their admirable description of the fossils MM d'Archiac and de Verneuil have but to add the one plate of the few so-called Silurian fossils, to their thirteen plates of true Devonian types, and all the general features of our labors will be in harmony with subsequent observations." *

LOWER DEVONIC OF GERMANY AND THE AMERICAN EQUIVALENTS

Views of writers as to its extent, character, and divisions.—Writing of the Lower Devonic of the Rhine, Kayser says:

> "This consists of at least 10,000 feet of sandy and clayey beds, almost entirely free from lime. The fossils which occur in it are almost always mere stone-casts. . . . They are generally rare, and are found only in isolated beds, which are often separated by many hundred feet of practically unfossiliferous rock. The fauna consists chiefly of Brachiopoda. The only other important forms are Lamellibranchs, Crinoids, and some Trilobites and Gasteropods, while Cephalopods and Corals are few in number. Some species . . . go through the whole, or almost the whole, series of beds, whilst others have a more restricted range. In general the constitution of the fauna points to a shallow sea, and the ripple-marks frequently met with at all horizons also speak in favor of this view." †

Frech ‡ writes that students of Rhenish geology are agreed on the following divisions of the Lower Devonic of Germany, which have for their bases four species of prevalent brachiopods:

4. Zone of *Spirifer paradoxus*	*c.* Zone with *S. speciosus* = Red ironstone. *b.* Upper Coblenzian. *a.* Coblenz quartzite.	
3. Zone of *Spirifer hercyniæ*	Lower Coblenz beds.	*b.* Lower Coblenzian. *a.* Porphyroid and Grauwacke of Sendorf.
2. Zone of *Spirifer primævus*	Siegen. Grauwacke.	*b.* Hunsrück schiefer. *a.* Taunus quartzite.
1. Zone of *Spirifer mercuri*	Gedinnian.	
	Taunus.	Sericitglimmer schiefer. Taunus phyllite.

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* Murchison's Siluria, pp. 365, 366.

†Kayser's Text-book, 1893, p. 92.

‡ Lethæa geognostica, 1 Theil, 2 Band, 1 Lief., Stuttgart, 1897.

The following German Lower Devonic faunas and their American equivalents are based on Frech's "*Lethæa geognostica*" (1897). The lists do not indicate the entire faunas.

1. *Gedinnian, fauna of the lowest Lower Devonic, or zone of Spirifer mercuri*

Germany.	American.
Orthis verneuili (cf. *O. elegantula*).	*O.* (*Dalmanella*) *planiconvexa* or *quadrans* Hall.
Spirifer mercuri Gosselet.	*S. perlamellosus* Hall.
Rensselæria strigiceps Roemer (this is no Rensselæria, probably a pentameroid).	
Grammysia deornata.	
Tentaculites irregularis de Koninck.	
Beyrichia richteri de Koninck.	
Primitia jonesi de Koninck.	
Homalonotus richteri de Koninck.	

This meager fauna occurs near the base of the Gedinnian, and there is nothing in it that can be successfully compared with American Devonic horizons. The few American species cited are of Lower Helderberg age, and while the German Gedinnian may be the equivalent, it seems best at present to defer a positive correlation.

2. *Siegen, fauna of the Siegen grauwacke, or zone of Spirifer primævus*

Germany.	American.
Chonetes sarcinulatus.	*Chonetes melonica* Billings.
Orthis personata Krantz.	
Orthis circularis Schnur.	
Strophomena murchisoni Verneuil.	
Strophomena sedgwicki Verneuil.	
Streptorhynchus gigas McCoy.	*Stropheodonta magniventra* Hall. (Frech compares *Hipparionyx proximus* Vanuxem.)
Cyrtina heteroclita Defrance.	*C. rostrata* Hall, *C. affinis* Billings.
Spirifer primævus Steininger.	*S. murchisoni* Castelnau or *S. arrectus* Hall.
Spirifer hystericus Schlotheim (= *S. micropterus* Goldfuss).	
Spirifer bishofi Giebel.	This form of Spirifer, with the fold and sinus somewhat plicated, does not begin in America before the Oriskany.
Athyris undata Defrance.	This is an Athyris of which *A. fultonensis* of the Middle Devonic is the best known.
Rhynchonella daleidensis F. Roemer.	

Germany.	American.
Rhynchonella pengelliana Davidson.	*Camarotœchia speciosa* (Hall).
Tropidoleptus rhenanus Frech.	
Rensselæria strigiceps F. Roemer (not a Rensselæria, probably a pentameroid).	
Rensselæria crassicosta Koch.	
Megalanteris archiaci.	*M. ovalis* Hall.
Palæopinna gigantea Krantz.	*P. flabellum* Hall.
Numerous pelecypoda.	Pelecypoda rare.
Platyceroids rare.	Platyceroids common.
Homalonotus ornatus C. Koch.	
Homalonotus planus Sandberger.	*H. major* Whitfield.
Homalonotus roemeri de Koninck.	*H. vanuxemi* Hall.
Homalonotus aculeatus C. Koch.	
Phacops ferdinandi Kayser.	*P. cristata* Hall.
Dalmania (*Odontocheile*) *rhenana* Kayser.	*D.* (*O.*) *pleuroptyx* (Green).
Cryphæus limbatus Schlüter.	American species of Cryphæus begin in the Middle Devonic.
Many crinoids and starfishes.	Crinoids rare; starfishes none.
Tentaculites grandis.	*Tentaculites acula* Hall.

In this fauna there is marked evidence for purposes of correlation. Brachiopods are numerous and often of large size, a degree of development also attained in the American Oriskany. The principal American species of this horizon and their equivalents in the Siegen grauwacke are shown as follows:

American.	Siegen.
Stropheodonta magniventra Hall.	*Streptorhynchus gigas* McCoy.
Camarotœchia speciosa Hall.	*Rhynchonella pengelliana* Davidson.
Crytina rostrata Hall and *C. affinis* Billings.	*C. heteroclita* Defrance.
Spirifer murchisoni Castelnau.	*S. primævus* Steininger.
Spirifer arenosus Conrad.	A poor representative in *S. bishofi* Giebel.
Meganteris ovalis Hall.	*M. archiaci.*
Palæopinna flabellum Hall.	*P. gigantea* Krantz.
Dalmanites (*Odontocheile*) *pleuroptyx* Green.	*D.* (*O.*) *rhenana* Kayser.
Tentaculites elongatus Hall.	*T. grandis.*

From this evidence and the further fact that zone 3, or Lower Coblenzian, does not clearly indicate the Oriskany, but a rather higher horizon, it follows that the Siegen grauwacke and the American Oriskany are fairly harmonious in their faunas. Frech correlates the Oriskany with the "Spirifer sandstone" of the Lower Coblenzian. This view places the Oriskany near the top of zone 3 (see page 266), a considerably higher or younger position than that given by the present writer.

Again, if the Hercynian fauna of the Lower Wieder Schiefer, described by Kayser,* is brought into the comparison, a fauna is met which also strongly recalls the Oriskany as well as the Lower Helderberg.

The brachiopods are the predominating fossils, with the long-hinged species of Spirifer in well developed forms. The Oriskany types are *S. decheni*, *S. ilsæ* (the representatives of the American *S. murchisoni* Castelnau and *S. arrectus* Hall); *S. nerei*, var., *S. hercyniæ* (closely related to *S. cumberlandiæ* and *S. tribulis*). Another Hercyn Spirifer, *S. bishofi*, may be compared with the Oriskany species *S. arenosus*, one of the most characteristic Spirifers in the introduction of the plicated fold and sinus. Of Lower Helderberg Spirifers, *S. macropleura* may be compared with the Hercyn *S. jaschei* and *S. sp.* (figure 6 of plate xxi). On the other hand, such species as *S. togatus* and *S. sericeus* recall *S. radiatus*, clearly a remnant of the Siluric fauna, but not of that age because of the far greater size attained by these forms.

Another Oriskany reminder is Meganteris figured by Kayser. This species is far larger than *M. ovalis* and as large as *Rensselæria ovoides*, a very closely related form. However, since it is the only terebratuloid in this, the true Hercyn fauna, the paucity is most marked when compared with the Oriskany or even with the Lower Helderberg. The Hercyn pentameroids are in harmony with those of the Lower Helderberg, while the rhynchonelloids are unlike any American facies. In a number of species the latter appear to be ancestors of *Hypothyris cuboides* of the Middle Devonic.

When the Hercyn Brachiopoda of the meristelloid family is examined, there is seen to be a marked paucity of species, especially when compared with the Lower Helderberg. The same is true of the Retzias, and particularly the orthoids. On the other hand, the presence of *Atrypa aspera* in the Hercyn is that of a form first appearing in the Corniferous or Middle Devonic.

The strophomenoids are non-committal, while the presence of several species of Chonetes, some of which attained a size above the average, denotes the Middle Devonic. Craniella is also rather indicative of a horizon above the Lower Helderberg.

From this summary of the brachiopods the conclusion is reached that the Hercyn species, if of one fauna, indicate an age not as old as the Lower Helderberg and probably not much younger than the later Oriskany.

With few exceptions, the Hercyn trilobites are those of the Lower Helderberg and Lower Oriskany. The exceptions are the presence of Harpes, a remnant of Ordovicic or Champlainic times, and the occurrence of Cryphæus, a genus first appearing in America in the Middle

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*Die Fauna der ältesten Devon-Ablagerungen des Harzes, Abh. z. geolog., Specialkarte von Preussen, Band ii, Heft 4, 1878.

Devonic. The great abundance of Phacops is characteristic of European faunas, and is in harmony with Lower Devonic development. The Hercyn trilobites are unmistakably of Devonic age, and seem to find their nearest relatives in the Lower Helderberg, but apparently more directly in the Lower Oriskany.

The presence of large fish spines and teeth in the Hercyn is strongly indicative of the Devonic, as well as of a development younger than anything known in the Lower Helderberg, and is more in harmony with the American Corniferous. Moreover, these Hercyn fish remains do not agree with those from the Siluric of England.

There is nothing in American Lower Devonic horizons to be compared with the Goniatite development of the Hercyn. These shells do not make an abundant appearance in American faunas until well into the Middle Devonic, and they give the Hercyn a strong and unmistakable Devonic aspect.*

The gastropods of the Hercyn point to the Lower Helderberg, but it should be borne in mind that these are nearly all capulids. Their size and the abundance of species, however, will also agree with the Oriskany age. The pelecypods are younger than the Lower Helderberg, and since but very few Oriskany species of this class are known, no direct comparisons can be instituted. The supposed occurrence of a typical Siluric graptolite zone near the top of the Hartz Hercyn gave it a very ancient aspect and a very remarkable life combination. However, from the work of Tullberg and Denckmann, it is now known that this zone is of Siluric age.†

From the foregoing review of the typical Hercyn fauna it is clear that while it contains a number of Siluric types, yet its general development, particularly the large size of many of its individuals, is not to be correlated directly with the Lower Helderberg. On the whole it appears to agree best with the Oriskany. If, in this connection, it is borne in mind that the Upper Oriskany is everywhere a shore deposit—coarse sands and shales—and has a decidedly littoral fauna, while the Hercyn is derived from limestone (the Goniatites indicating deeper water), one of the causes for the marked difference in these faunas is made apparent. On the other hand, the Lower Helderberg fauna, while not of a very deep sea, is deeper than the Oriskany, and if the former is of the same age as the Hercyn, then more harmony might be expected than exists between them. These various reasons result in the conclusion that the Hercyn fauna is to be correlated rather with the Oriskany than with the Lower Helderberg. Frech would place it a little higher, because he regards it as a certain equivalent of the Lower Coblenzian, and probably also of the Siegen grauwacke. This view, joined to that of the writer's, makes the Hercyn fauna of the Lower Wieder Schiefer the probable equivalent of the American Oriskany, although it may occupy a somewhat younger position in the time scale.

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*See remarks on the Goniatites of étage F_2, Konieprussian of Bohemia, p. 265.

†See Frech : Lethæa geognostica, 1 Theil, 2 Band, 1897, pp. 117, 193.

Another related fauna and one derived from calcareous beds is that described by Barrois* from the hamlet of Erbray, in the lower Loire. On examining the plates illustrating this fauna, it soon becomes apparent that the Erbray fauna has the general aspect of the Hartz Hercyn, but the faunal assemblage is a different one and has a younger appearance, which is due to the scarcity of orthids, being almost restricted to *O.* (*Rhipidomella*) *palliata*, a local and distinct development. The Stropheodontas are rather those of the American Middle Devonic, and the same is true of many of the Rhynchonellas, athyroids, and centronelloids. The Spirifers, as a rule, find their analogues in the Oriskany and Middle Devonic, while the large *Megalanteris inornata* and *M. deshayesii* point to the Oriskany. Indications of the older faunas occur in the strongly plicated pentameroids, some of the Rhynchonellas, the Meristellas, and *Spirifer bisulcata*. A decided Devonic aspect is marked in the trilobites, for *Cryphæus* is here well developed and the Dalmanites (Odontocheile) section is absent. The platyceroids agree both with the Lower Helderberg and Oriskany, while the other gastropods accord with forms best developed in the Siluric. The great development of Conocardium in the Erbray fauna gives it its character, yet the forms are all small, and therefore do not have the aspect of higher Devonic species. The abundance of cup corals and Acervularia is also a decided characteristic of American Middle Devonic faunas.

It is unsafe to make definite correlations when faunas are so different as that of Erbray and those of the American Lower Devonic. It is true that the Erbray fauna and that of the Lower Helderberg are from limestones, but the Oriskany fauna is nearly everywhere found in a coarse sandstone, while practically nothing is known of the life of the Cauda-galli (= Esopus). However, the above summary of the Erbray fauna shows that the development is unlike that of the American Lower Helderberg. While the latter brings to mind some of Erbray, still the developmental progression is rather that seen in the Oriskany, and probably also of the time interval represented by the Cauda-galli.

Recently Frech † has discussed the position of this fauna and points out that there are three fossil zones the exact relation of which, one to another, is not yet fully established. He correlates the Erbray fauna with all of the *Spirifer hercyniæ* zone, or the Lower Coblenzian, and the upper portion of the Siegen of the Rhine. This is exactly the view arrived at by the writer before he knew of Frech's conclusions.

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* Faune du Calcaire d'Erbray; Cont. a l'étude du Terrain dévonien. Mém. Soc. géol. du Nord, iii, April, 1889.

† Lethæa geognostica, p. 195, and table xiii.

In the Lower Devonic of England, at Looe, in Cornwall, a fauna occurs which Kayser[*] says is in harmony with that of the Siegen grauwacke. As far as the writer is able to judge, this correlation is not only correct for the Rhineland, but also is in harmony with the Oriskany. Possibly a similar fauna occurs in the Lynton slates of North Devon, England.

In this review of the Lower Devonic faunas of Europe, there are none which seem to be the direct equivalent of the American Lower Helderberg. Therefore a review will now be made of Barrande's étage F, often regarded as lowest Lower Devonic.

The greatest number of American Lower Helderberg specific equivalents exist among the brachiopods. These are in the Konieprussian of étage F_2. However, it should here be borne in mind that étage F_2 contains two distinct zones—stratigraphically, lithologically, and paleontologically—the Konieprussian and Menian. This has recently been pointed out by Kayser and Holzappel,[†] and they correlate the Menian limestones with the basal Middle Devonic of the Eifel, or the beds characterized by *Spirifer cultrijugatus.* This horizon appears to be about that of the Corniferous. Frech[‡] tabulates the lower Devonic of Bohemia as follows:

"G_1. Nodular limestone of Tetin with Odontocheile.

Deep sea.

F_2 in part. Red flaggy limestone of Menian (= Greifenstein) with *Agoniatites fidelis*, crinoidal limestone with trilobites, Goniatites, smooth brachiopods.
Fairly deep sea. (Oriskany (part), Cauda-galli, and Schoharie grit).

F_2 in part. White coral-reef limestone of Koniepruss, massive, with numerous corals, brachiopods, capulids, and nests of trilobites.
Shallow sea. (Lower Helderberg and Oriskany.)

F_1. Black flaggy limestone of Kosorsch with deep-sea sponges, palæoconchs, and *Hercynella bohemica.*
Very deep sea. (Lower Helderberg.)

E_2. Upper Silurian."

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[*] Text-book of Comp. Geology, p. 105.

[†] Jahrb. der k. k. geolog. Reichsanstalt, Band 44, Heft 3, 1894.

[‡] Lethæa geognostica, pp. 188, 256.

The succeeding list of specific equivalents for Bohemia and the Lower Helderberg of New York was not prepared to fit the case in hand, but is the outcome of an examination of Barrande's fine plates. The writer has often collected in the Lower Helderberg and Oriskany, and has studied their faunas for ten years. In going over Barrande's plates he was surprised to find that the brachiopods in the two regions were very similar. A careful perusal of the list here given will show that the most important Lower Helderberg brachiopods have direct equivalents in the Konieprussian. Each region has, of course, its own development, and the common forms of one region may be rare in the other. For instance, in America the great development of the subgenera of Orthis—Dalmanella and Rhipidomella—have but little diversity in étage F_2, while here the spire-bearing families Meristellidæ and Athyridæ have a far greater diversity. The same is also true for the Rhynchonellidæ, although these shells are varied and abundant in the Lower Helderberg. These are the local aspects of widely separated faunas, however, and when such similarities are detected as are indicated in the following list, they should be given their full value:

Bohemia, étage F_2.	Lower Helderberg.
Discina radians Barrande.	*Orbiculoidea discus* Hall.
Orthis palliata B. (Pl. 58).	*O.* (*Dalmanella*) *perelegans* Hall.
Orthis pinguissina B.	*O.* (*D.*) *quadrans* (Hall).
Orthis præcursor B.	*O.* (*Schizophoria*) *multistriata* Hall.
Strophomena rhomboidalis (Wilckens).	*Leptæna rhomboidalis.*
Strophomena bohemica B.	*Strophonella punctulifera* (Conrad).
Strophomena phillipsi B.	*Stropheodonta varistriata arata* Hall.
Strophomena sowerbyi B.	*Stropheodonta becki* Hall.
Strophomena æsopea B.	*Orthothetes deformis* Hall.
Chonetes venustus B.	*Chonostrophia helderbergiæ* H. & C.
Chonetes inconstans B.	*Anoplia nucleata* Hall.
Chonetes squamatulus B.	
Pentamerus sieberi v. Buch.	*Gypidula galeata* (Dalman).
Pentamerus optatus B.	
Pentamerus firmus B.	? *Anastrophia verneuili* (Hall).
Rhynchonella eucharis B.	*Eatonia medialis* (Vanuxem).
Atrypa assula B.	*Eatonia peculiaris* (Conrad).
Rhynchonella phœnix B.	*Rhynchonella semiplicata* Conrad.
Spirifer nerei B. F_1, F_2.	*Spirifer concinnus* Hall.
Cyrtina heteroclita Defrance.	*Cyrtina dalmani* (Hall).
Atrypa reticularis Linné.	Same species and local development.
Atrypa semiorbis B.	*Atrypina imbricata* Hall.
Merista herculea B.	*Merista typus* Hall.
Merista minuscula B.	
Atrypa compressa B.	*Meristella bella* Hall.
Atrypa inelegans B.	*Nucleospira ventricosa* Hall.

Bohemia, étage F_2.	Lower Helderberg.
Retzia haidingeri B.	*Rhynchospira formosa* Hall. *Rhynchospira globosa* Hall.
Atrypa eurydice B.	*Rensselæria mutabilis* Hall.
Retzia melonica B. (Pl. 141).	Probably another Rensselæria of Lower Helderberg development.
Dalmanites hausmanni Brongniart. G.	*D.* (*Odontocheile*) *micrurus* (Green).
Acidaspis monstrosa B. G_1.	*Acidaspis tuberculata* (Conrad).
Phacops breviceps F_2.	*Phacops logani* Hall.
Fenestella and Hemitrypa in abundant development in étage F.	An abundant development of these forms in the Lower Helderberg.
Actinostroma, Stromatopora, and Clathrodictyon in numerous examples in F.	Syringostroma and Clathrodictyon in the Lower Pentamerus limestone.

The foregoing table of equivalents leads the writer to regard the Konieprussian and the Lower Helderberg as closely related, as well as the oldest well described Lower Devonic brachiopod faunas. The great diversity of the fenestelloids in étage F is in harmony with a similar development in the Delthyris shale of the Lower Helderberg. The stromatoporoids are also in harmony with this view. The trilobites do not oppose this correlation, but two characteristic species of the Lower Helderberg—*Dalmanites micrurus* and *Acidaspis tuberculata*—find their equivalents in the next higher zone, or étage G. Barrande does not figure the gastropods and pelecypods of Bohemia, and the writer can therefore make no comparisons. The Goniatites said to be of étage F_2, described by Barrande, are now known to belong in a zone the equivalent of G (see Frech's table on page 263), and therefore do not affect the Lower Helderberg fauna. Even if they occurred in the Konieprussian fauna under review, the fact should be borne in mind that not a single Goniatite is known in America prior to the Corniferous, and that there is but a meager representation in any American Middle Devonic horizon. The weight of this argument, therefore, loses its force in point of correlation. On the other hand, of the 6 species of Goniatites said by Barrande to be from étage F_2, but 2 are restricted to that horizon—*G. solus* and *Agoniatites fidelis*—while the other 4 also occur in G_3—*G. plebius* B. = *Anarcestes latiseptatus* (Beyrich), *Agoniatites verna*, *Anarcestes crispus*, and *Agoniatites tabuloides*—and 2 of these persist into H_1—*Anarcestes latiseptatus* (Beyrich) and *Agoniatites verna*. These species thus show that they have no particular stratigraphic value beyond the fact already mentioned, which seems strong proof for a Devonic facies. The writer therefore concludes that the Konieprussian (F_2) and the Lower Helderberg are the equivalents of each other and represent the best known lowest Lower Devonic faunas.

This view differs from that of Frech, for he correlates F_1 and the F_2 Konieprussian with the Lower Helderberg and Oriskany. It seems to the writer that in Bohemia there is no equivalent for the littoral Oriskany, and that between F_2 Konieprussian and F_2 Menian a faunal hiatus exists. Étage F_2 Menian and G seem to conform to the American Schoharie grit and Corniferous. However, the writer does not insist on all these correlations, but merely wishes to point out that the Lower Helderberg fauna finds its best representative in the Konieprussian of Bohemia. The latter and étage F are now generally regarded by European stratigraphers as lowest Lower Devonic.

Barrande long ago recognized a faunal resemblance between his étage E and the Wenlock of England, although he also referred his étages F, G, and H to the Siluric system. In Barrande's time, the Cambric as a system was almost unknown, and even today Geikie* writes:

> "For myself, I repeat what I have said in previous editions of this text-book, that the most natural and logical classification is to group Barrande's three faunas [now Cambric, Ordovicic, and Siluric] as one system, which in accordance with the laws of priority should be called Silurian."

This is also the opinion of M Hebert,† F. Schmidt,‡ and De Lapparent.§ If in this connection the fact is also borne in mind that the Lower Devonic of Devonshire and of the Rhineland consists almost wholly of sandy and slaty beds whose fauna at that time was little known, thus contrasting with the well known, abundant, and almost sequential faunas from the Primordial to étage H of Bohemia, it can be partially understood why étages F, G, and H are correlated by Barrande with the Upper Silurian. Again, if the great faunal resemblances or the gradually modifying fauna of the étage E (Wenlock) into F and thence G and H are noted, another good reason appears; and, finally, if remembered that the upper limit of Murchison's Upper Silurian fauna was essentially the Wenlock, and that the known Devonic fauna of his time was practically that of the Middle Devonic, the argument is complete for Barrande's reference of étages F, G, and H to the Silurian. These facts formerly had, and still have their influence in America. At first the Oriskany and Lower Helderberg were referred to the Silurian. After De Verneuil and Sharpe's visit to America in 1847, the Oriskany was referred to the Devonic (Hall, 1858), and this then came to be the generally recognized base for this system in the United States. ||

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* Text-book of Geology, 1893, p. 727.

† Bull. Soc. Géol. France, 3 ser., vol. xi, 1882, p. 34.

‡ Quar. Jour. Geol. Soc. London, vol. 38, 1882, p. 515.

§ Traité de Géologie, 3d ed., 1893.

|| Sharpe: Quar. Jour. Geol. Soc. London, vol. iv, 1847, pp. 145–181.
De Verneuil: Soc. Géol. de France, 2d ser., vol. iv, 1847, pp. 646–709.
Hall, Foster, and Whitney's Rept. on Lake Superior, pt. ii, pp. 285–318.

3. *Lower Coblenzian, zone of Spirifer hercyniæ*

Coblenzian.	American.
Orthis hysterita Grim.	*O.* (*Schizophoria*) *striatula.*
Orthis circularis Sowerby.	
Strophomena plicata Sowerby.	
Strophomena explanata Schnur.	*Stropheodonta* (*Leptostrophia*) *magnifica* Hall.
Chonetes sarcinulatus Schlotheim.	*C. melonica* Billings and *C. coronatus* Conrad.
Chonetes dilatatus de Koninck (probably Stropheodonta).	
Chonetes plebeus Schnur.	
Rhynchonella daleidensis F. Roemer.	Nothing like it.
Rhynchonella dannenbergi Kayser.	Frech compares *R. multistriata* Hall. (Of the Oriskany.)
Rhynchonella (*Wilsonia*) *pila* Schnur.	Nothing like it.
Spirifer subcuspidatus Schnur.	*S. fornacula* Hall, *S. medialis* Hall.
Spirifer carinatus Schnur.	Similar with the Hamilton *S. granulifer* Conrad.
Spirifer hercyniæ Giebel.	*S. cumberlandia* Hall.
Spirifer arduensis Schnur.	*S. duodenaria* Conrad.
Athyris undata Defrance.	The nearest is the Hamilton *A. spiriferoides* (Eaton).
Athyris ferronensis Verneuil.	Nothing like it.
Anoplotheca venusta Schnur.	
Megalanteris archiaci Verneuil.	
Rensselæria strigiceps F. Roemer.	Frech compares *R. ovoides* (Eaton).
Tropidoleptus rhenanus Frech.	
Numerous pelecypoda.	
Few gastropods.	
Homalonotus armatus Burmeister.	No spiniferous American species.
Homalonotus rhenanus C. Koch.	*H. vanuxemi* Hall.
Homalonotus ornatus Sandberger.	No ornate American species.
Homalonotus roemeri.	

This fauna does not readily correlate with any American horizon. Frech, however, says "the Lower Coblenz strata, consisting of grauwacke and slates with interbedded quartzites, form in a developmental aspect an unchanged continuance of that of the Siegen grauwacke."* This horizon is apparently not far removed from the later Oriskany and may be the equivalent of that and the Cauda-galli.

4. *Upper Coblenzian, zone of Spirifer paradoxus*

The fauna here is a very extensive one, and if the American reader will look at Frech's † plate 24*b* he will not hesitate to pronounce the age of that

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* Lethæa geognostica, 1897, p. 146.
† Ibid.

Upper Coblenz slab the equivalent of the Hamilton or Middle Devonic beds. However, the present writer does not mean more than faunal resemblance, certainly not synchronous equivalence. In any event, the Upper Coblenzian has nothing to do with the Oriskany, but rather with the American Corniferous and Hamilton. These divisions are here regarded as members of the American Middle Devonic.

A very similar result is obtained by examining the plates illustrating "Die Fauna des Hauptquarzits" of the Hartz, by Kayser.* This horizon is correlated with the Upper Coblenzian of the Rhine. With very few exceptions the species there illustrated find their nearest relatives in the American Hamilton. A few of the brachiopods, however, agree best with Corniferous species.

CONCLUSIONS

If the faunas of the Hercyn (Kayser) and Siegen are the equivalents of the Oriskany, then beds the age of the Lower Helderberg are to be found in the Gedinnian and Taunus, or zone of *Spirifer mercuri*, in the Rhineland. This fauna, however, is a very small one, and the writer does not feel warranted in making a correlation of value. But the Gedinnian of Germany and France is often correlated with étage F of Bohemia. In any event, the Lower Helderberg has its equivalent in étage F_2 Konieprussian. It will be shown in the next chapter that the Lower Helderberg fauna has decided Devonic characteristics and very little of typical, or Murchisonian, Upper Silurian.

The Hercyn of the Hartz and the Siegen grauwacke of the Rhineland (possibly, also, the Linton slates of the Lower Devonic of England) appear to be equivalents of the Oriskany. Both these faunas have a brachiopod development which unmistakably points to the younger Oriskany, but there is also a facies which finds its nearest expression in America in the older Oriskany. In this connection it may be pointed out that de Verneuil,† after his visit to America, published the view, in 1847, that the Oriskany is Devonic, regarding it as the equivalent of the fossiliferous schists (Spirifer sandstone) of the Rhine. The sediments of the later Oriskany are very coarse, and the older Oriskany is as yet practically unworked paleontologically. Therefore, at present large brachiopods chiefly constitute the known Oriskany fauna. This expression is also seen in the Hercyn and Siegen faunas. On the other hand, the German sediments are less coarse, presenting conditions for a different faunal development, while the waters were also probably deeper.

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[*] Abh. d. k. preuss. geol. Landesanstalt, n. ser., Theil 1, 1889.

[†] Bull. Soc. Géol. de France, 2d ser., vol. iv, 1847, pp. 646–709; see also Hall's translation, Amer. Jour. Sci., 1848, pp. 177–178.

This difference is shown in the abundance of pelecypods and the presence of Goniatites, while in the finest sediments, the slates, an abundant and varied local fauna of crinoids and starfishes is present.

The Erbray fauna described by Barrois may be the equivalent of the Oriskany or of the Upper Oriskany and Cauda-galli. In any event, it appears to be younger than the typical Hercyn and not as young as the Lower Coblenzian.

The latter does not appear to the writer to be the equivalent of the Oriskany, as stated by Frech, but brings to mind some portions of the Upper Helderberg. It may represent either the Cauda-galli fauna, which as such is there unknown, or the Schoharie grit. In any event, it seems clear that the Upper Coblenzian has a fauna which American paleontologists may safely conclude to be very much like that of the Hamilton, although it probably is not quite so recent.

American Lower Devonic[*]

HELDERBERGIAN SUBDIVISIONS[†]

This series of strata is generally known as the Lower Helderberg group, and "has been so termed from its very complete development along the base of the Helderberg mountains, constituting in this part of New York an important fossiliferous group. In some parts of the Helderberg mountains, and along the Hudson river at Rondout, and at Schoharie and elsewhere, the lowermost beds of this group [Tentaculite or Manlius limestone] rest directly on the Waterlime beds, which we regard as the uppermost member of the Onondaga salt group."[‡]

The Helderbergian series in New York reposes on the Manlius (Tentaculite) limestone, and in places begins with a thin mass of limestone containing Stromatopora, which is known as the Stromatopora limestone. The next persistent horizon is the Coeymans (Lower Pentamerus) limestone, "charged with great numbers of the broken shells of *Penta-*

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[*] A map giving the known distribution of the Helderbergian and of the Cayugan and Niagaran to 1874 was prepared by Professor James Hall, and will be found accompanying a paper entitled "The Niagara and Lower Helderberg groups; their relations, and geographical distribution in the United States and Canada." See Twenty-seventh Ann. Rept. N. Y. State Mus. Nat. Hist., 1875, pp. 117–131.

[†] The terminology here adopted is that of Clarke and Schuchert, Science, vol. x, December 15, 1899, pp. 874–878. It is as follows:

Eodevonic	Oriskanian.	Oriskany beds.
	Helderbergian	Kingston beds (= Upper shaly limestone).
		Becraft limestone (= Upper Pentamerus limestone).
		New Scotland beds (= Delthyris shaly limestone).
		Coeymans limestone (= Lower Pentamerus limestone).

[‡] Hall: Paleontology of New York, vol. iii, 1859, p. 33.

merus [*Gypidula*] *galeatus.*"* In Otsego county this limestone has a thickness of not less than 80 feet.

The Coeymans limestone "graduates above into a shaly formation, which was designated in the New York Reports as the Delthyris shaly limestone, from the abundance of this genus of fossils [Delthyris = Spirifer]."† The "Delthyris shaly limestone" or New Scotland beds is the most prolific in fossils, not less than 298 species having been found in New York alone.

The upper member of the Helderbergian is generally known in New York as the Upper Pentamerus limestone. Vanuxem named it the "Scutella limestone," because of the presence of certain large crinoidal plates, while Gebhard called it the "Sparry limestone," owing to its strong crystalline nature. Darton, with Hall's consent, has recently renamed it "Becraft limestone," a name here adopted.

All these rocks are well exposed in the Helderberg hills of New York, particularly in Albany and Schoharie counties, where they have a thickness of from 300 to 400 feet, but thin out rapidly toward the west. There is "scarcely any evidence of their existence in New York west of Oneida county."‡

Following the Helderberg hills in a southwesterly direction "through Pennsylvania, Maryland, Virginia, and Tennessee, we everywhere find the same group of strata, and bearing everywhere more or less the same species of fossils. . . . In some localities in the middle and southern [southwestern] parts of Tennessee, the collections of fossils are so like those from the Helderberg mountains, near Albany, that but for their color and here and there a difference in the development of certain forms, there would be little to distinguish the two localities."§ The same is also true of the Helderbergian of Indian Territory.

In Monroe county, in eastern Pennsylvania, the Helderbergian has a thickness of about 600 feet, but thins westward, and in Perry county is only 350 feet thick. In Pennsylvania these beds are known as division number 6, and locally as the "Stormville shales." The latter "grow buff and sandy when traced westward from the center of Monroe county, and, as seems most probable, become continually coarser, until they are consolidated with the Oriskany sandstone."||

In western Maryland, the Helderbergian series is represented in the "Upper limestone series" of the Lewiston formation, and appears to be more extensively developed stratigraphically than in any other region

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* Hall, 1859.

† Hall, 1859, p. 33.

‡ Hall, 1859, p. 37.

§ Hall, 1859, pp. 37–38.

|| I. C. White, Geol. Survey of Pa., vol. C C, 1882, p. 132.

of the United States. The writer recently spent three days examining these deposits and the fossils gathered by Mr Robert H. Gordon. No complete section of the Helderbergian was seen in any one place, but there was sufficient to show that this series is probably not less than 500 feet thick; also that the four zones of the New York division are present in the region of Cumberland, and that the Helderbergian apparently passes without break into the Oriskany. In New York, the Helderbergian is generally followed by a few feet of Oriskany, which represent the later portion and not the whole of this formation. The following is the Helderbergian and Oriskanian section about Cumberland, as made out by the writer, while the fossils of the former series in Mr Gordon's collection are listed beyond:

Section at the "Devil's Back Bone," Kreighbaum Station, Baltimore and Ohio Railroad

Marcellus shale.	
Oriskany	Top not seen here, but elsewhere is a coarse sandstone. Dark blue, arenaceous, heavy bedded limestone, abounding above in *Spirifer arenosus*, *Stropheodonta magnifica*, and below in *S. arrectus* and *Chonostrophia complanata*. Thickness about 150 feet.
Kingston (or Oriskany)	Dark blue, arenaceous limestone with chert zones. Heavy beds above passing into thin beds. No fossils were seen. Thickness about 125 feet.
New Scotland and Becraft.	Thin bedded, shaly limestone and shale with chert, abounding in New Scotland fossils. Shales with *Anoplotheca flabellites* near the top. Thickness about 75 feet. The fossils known from this zone are *Zaphrentis*, *Leptæna rhomboidalis*, *Stropheodonta beckii*, *Orthothetes radiata ?* *Orthis perelegans*, *Spirifer perlamellosus*, *S. cyclopterus*, *S. micropleura*, *Trematospira perforata*, *T.* near *multistriata*, *Eatonia medialis*, *Rhynchonella villicata ?* *Phacops logani*, *Dalmanites micrurus*, and *D. pleuroptyx*.
Railroad watch-house here.	
Coeymans limestone	Heavy bedded limestone with chert. Fossils abundant, *Gypidula galeata*, etcetera. Thickness about 60 feet. Heavy and thin bedded bluish to yellowish limestone with chert zones. A well developed Stromatopora zone at the top and bottom; also *G. galeata*, corals, and crinoids. Thickness about 60 feet.

Transition	Thin bedded bluish limestone with zones of shale. Bryozoa abundant. Near the top occurs a small variety of *G. galeata* and *Favosites helderbergiæ*, and toward the bottom *Leperditia alta*, *Goniophora dubia*, and *Spirifer vanuxemi*. Thickness about 160 feet.

Base not seen.

Section at Rose Hill, Baltimore and Ohio Railroad (*main line*)

Top not seen.

Manlius limestone	A series of heavy to thin bedded, light blue limestones resembling water limestones. The series is fossiliferous throughout in narrow zones. Has *Tentaculites gyracanthus*, *Leperditia fabulites*, *Beyrichia notata*, other Ostracods, *Rhynchospira* near *globosa*, *Meristella*, a small species very common; *Orthis* near *perelegans*, and poor Bryozoa. Thickness about 175 feet. Base not seen.

Salina.

In southwestern Virginia the Helderbergian occurs in Lee, Wise, and Scott counties, and is described by Professor J. J. Stevenson[*] as follows:

"The Lower Helderberg.—The rocks of this group are exposed in the Poor valley; on the western end of Wallens ridge; in the valley between Wallens ridge and Powell mountain, in the North Fork gap; and on the southeastern slope of Powell mountain beyond the gap. The exposures are very fair, and a complete section could be obtained without much difficulty.

"The estimated thickness is not far from 250 feet. For 70 feet from the bottom the series consists of limestones in beds from three to five feet, separated by shales in somewhat thicker layers. . . . Contains abundance of *Leperditia*. [This may be the Onondaga or Waterlime horizon of the Siluric.] Overlying this is a succession of coarse grained calcareous sandstones, shales, and silicious limestones. . . .

"The lower sandstone . . . seems to be made up almost wholly of casts of *Orthis oblata*, *Rhynchonella ventricosa*, and undetermined *Meristella*.

"The silicious limestone yielded *Aspidocrinus scutelliformis*, *Atrypa reticularis*, *Strophomena rhomboidalis*, *Spirifer cyclopterus*, *Rhynchonella nucleolata*, *Orthis oblata*, etcetera."

In eastern Tennessee, the Helderbergian is not known, but in the western part of the state these beds are from 20 to 100 feet thick. The fauna here is essentially that of the New Scotland beds of New York. In Missouri, the thickness is given as 175 feet, and in Union county, Illinois, the lower 200 feet of the "Clear Creek limestone" are assigned to the Helderbergian.

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[*] Proc. Am. Phil. Soc., August, 1880.

Until recently no other region for these strata was known south or west of Tennessee and eastern Missouri. In 1891 Mr Hill discovered and Professor Williams identified the Helderbergian in Indian Territory. The fauna there contains 40 species, and is given in another place on the authority of Doctor George H. Girty.* Mr Taff describes the Indian Territory outcrops as follows:

"Rocks of Lower Helderberg period, as far as known in Indian Territory, are limestones and occur in the Chickasaw Nation, near its east line, in townships 1 south, range 8 east, 2 south, range 8 east, and 1 north, range 7 east. The second and third localities are known from a few fossils collected from highly tilted limestones found between black shale which is unconformably disposed above and thicker beds of Silurian or Ordovician limestone resting below. The limestone in these two localities, the one upon the south side and the other upon the north side of an extensive area of Silurian and Ordovician limestone, bears westward through an unknown distance in the Chickasaw Nation. The Lower Helderberg in township 1 south, range 8 east, is in the Atoka quadrangle and has been surveyed and mapped. It occurs at the east end of an extensive area of limestone and sandstone, part of which is known to be Lower Silurian and Ordovician. This area of Lower Helderberg limestone is 4½ miles long north and south and is from ½ to 2½ miles wide. The beds dip eastwar atd a low angle, and are overlain unconformably upon the north, east, and south sides by black fissile shale, which includes beds of flint, chert, and limestone segregations.

"The collection of Lower Helderberg fossils discussed by Doctor G. H. Girty in the Nineteenth Annual Report of the United States Geological Survey were taken from this locality. The reference of these rocks to the Lower Helderberg is based upon and due to Doctor Girty's work.

"The Lower Helderberg limestone has an estimated thickness of 140 to 200 feet, and its strata may be divided into two and possibly three stratigraphic units. While the contrast between these units is not very great, it is sufficient to induce description. (1) From the highest stratum in contact with the black shale downward through 95 feet the beds are light yellow or white limestone, which are occasionally separated by marly layers. Many of these limestone strata contain flint and cherty concretions. In almost all the beds remains of fossil shells were observed, and many especially which contain chert and flint bear shells beautifully preserved in chalcedony. (2) Next below there are 50 feet of friable layers of yellow limestone interstratified with still softer marly beds. These beds are very fossiliferous, abounding in well preserved corals, trilobites, and brachiopods. (3) Continuing downward through 55 feet thicker beds of crumbling limestone are encountered, which have yielded no well preserved fossils. Some of these beds are granular limestone and contain fragments of fossils. These, as suggested by Doctor Girty, may prove to belong to the Niagara period, as do the beds immediately below.

"The rock below these non-fossiliferous beds is a massive, whitish, silicious, oolitic limestone 15 to 30 feet thick. It has yielded but few fossils and these Doctor Girty refers to types more nearly related to the Niagara than to the Lower Helderberg period.

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*Nineteenth Ann. Rep. U. S. Geol. Survey, 1899, pp. 546–550, 552–573.

"Below the oolitic limestone there are about 30 feet of shale which in turn rests upon Ordovician limestone."

Other Helderbergian areas are described by Dana as follows:

"The Saint Lawrence tidal waters of this period must have extended westward to the border of Vermont and Montreal and southward along the Connecticut valley. In Canada, in the line of the Connecticut valley, Lower Helderberg fossils occur in Dudswell and near lake Massawipi and Aylmer. They are also found in northern New Brunswick, northern Maine, near Square lake, and along the Gaspé-Worcester trough. They also occur in southern New Brunswick and near the coast in Pembroke, Maine, with many fossils, and in northern Nova Scotia, within the limits of the Acadian trough."*

A typical Helderbergian fauna is also known from Kennedy channel, latitude 80°–81° north, longitude 70° west. Doctor Hayes here collected the following species identified by Meek: †

Zaphrentis hayesii Meek.
Syringopora sp. undet.
Favosites sp. undet.
Leptæna rhomboidalis (Wilckens).
Strophonella headleyana Hall?
Stropheodonta beckii Hall?
Rhynchonella sp. undet.
Anoplotheca concava (Hall).
Spirifer perlamellosus Hall.
Loxonema (?) *kanei* Meek.
Orthoceras.
Illænus.

HELDERBERGIAN FAUNA

Relation to the Siluric.—From the appended list of the species of this fauna and their distribution, it is seen that no less than 426 are described, with 33 undescribed, in the Beecher collection. Sixteen of these, or about 3½ per cent, come from the Niagaran and Manlius formations. If the individual species are examined, it is seen that 5 have no particular stratigraphic value: *Favosites gotlandicus* Billings is probably a lax identification; *Halysites catenularia* is also known in the Trenton and Niagara; *Leptæna rhomboidalis* exists from the Trenton through nearly all the intermediate horizons into the base of the Lower Carbonic; *Orthothetes subplanus* belongs to a genus having no particular significance excepting its post-Ordovicic development, and *Atrypa reticularis* begins near the base of the Siluric, and is continuous throughout the Devonic. If the doubtful species and those not characteristic of the Siluric are eliminated, as *Favosites gotlandicus*, *Halysites catenularia*, *Atrypa reticularis*, and *Leptæna rhomboidalis*, the Helderbergian will be found to derive but 10 forms in its fauna of 459 species from the Siluric; *i. e.*, 3 from the Niagaran and 8 from the Manlius. This is a little more than 2 per cent.

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* Dana: Manual of Geology, 4th ed., 1896, p. 558.

† Amer. Jour. Sci., 1865, p. 31. The specimens are in the U. S. National Museum.

Everywhere in the Cayugan, there is a scarcity of normal marine life, and this is particularly true of the Salina and Rondout stages. The Molluscoidea and Mollusca are generally absent. On the other hand, the ostracods, phyllocarids, and particularly the eurypterids, are the prevalent fossils. With the exception of the ostracods, not a single species of phyllocarid or eurypterid is known in the Helderbergian in any of the areas from Maine to the Indian Territory.

With these facts there is presented a great paleontological break between the Siluric and Devonic at the top of the Cayugan group. The succumbing of the normal marine faunas of the Niagaran group is undoubtedly associated with the red gypsiferous and saliferous sediments of the Cayugan group. If the latter had a normal marine fauna instead of one of peculiar crustacea, the continuity of life from the Niagaran to the Helderbergian would be probably complete. However, in most areas outside of New York and Ohio, there is a great hiatus between the Niagaran and the Helderbergian, which tends to make a clear and easily discoverable line for field geologists in separating the Siluric from the Lower Devonic.

Relation to the Devonic.[*]—In New York, where the Helderbergian is best developed and its fauna well known, there are 364 described species, with 33 new ones in the Beecher collection. Of this fauna more than 9 per cent go into the Oriskanian (this fauna has 17 per cent of Helderbergian species). It is therefore evident that specific identity is greater between the Helderbergian and Oriskanian than between the former and the Siluric.[†]

Having examined the numerical specific relationships of the Helderbergian, its Siluric and Devonic aspects will now be pointed out. It is needless to go into great detail at this time, as Clarke[‡] did this work some years ago. Therefore the more prominent features only will be treated.

The trilobites are usually regarded as of first importance for stratigraphic correlation. In the Helderbergian there are the following genera or subgenera: *Homalonotus*, *Bronteus*, *Dalmanites*, *Probolium*, *Odontocheile*, *Phacops*, *Acidaspis*, *Lichas*, *Cordania*, *Proetus*, and *Cyphaspis*. This enumeration fails to present some of the most characteristic fossils of the American Siluric, as *Bumastus*, *Encrinurus*, *Sphærexochus*, *Cheirurus*, *Calymmene*, and particularly *Illænus* so prolific in species. Of the abundant Siluric eurypterids and of *Ceratiocaris*, none occur in the Helderbergian. On the other hand, the Helderbergian trilobites of the genera *Bronteus*, *Phacops*, *Acidaspis*, and *Cordania* have decided Devonic affinities, while *Dalmanites* (*Odontocheile*) is rather Devonic in development, although there are related species present in the Siluric. *Calymmene* again appears in the Onondaga.

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[*] The writer admits the unequal argument in contrasting the Helderbergian on one side with the Niagaran and on the other with the Oriskanian. The Helderbergian and Oriskanian have nearly continuous faunas, but between the former and the Niagaran intervenes the Cayugan group, of which a meager fauna is known. However, the essential question is, Has the Helderbergian a fauna more Devonic than Siluric in aspect?

[†] The Siluric Manlius limestone has 26 species. Of these 3 are also in the Coeymans and 3 in the New Scotland.

The Coeymans limestone has 58 species. Of these 15 (26 per cent) are also in the New Scotland beds, and 5 (or nearly 10 per cent) pass through into the Becraft limestone; 4 (or 7 per cent) also occur in the Oriskanian.

The New Scotland has 298 species. Of these 15 come from the Coeymans, while 29 (or 10 per cent) pass upward into the Becraft limestone, and 33 (or 11 per cent) also occur in the Oriskanian.

The Becraft limestone has 44 species, of which 29 come from the New Scotland, and 12 (or 27 per cent) pass into the Oriskanian above.

[‡] The Hercynian Question, Forty-second Ann Rept. N. Y. State Mus., 1889.

The brachiopods may also be regarded as of prime importance because of their wide distribution, abundance, and specific differentiation. In the Helderbergian, there are no less than 137 species. A Devonic aspect is indicated in the large size attained by most of the species, and the abundant specific development of the subgenera *Rhipidomella* and *Dalmanella*. *Christiania* and *Leptænisca* are genera in which the shell is anchored directly to some foreign object, but this feature is unknown in earlier faunas, and becomes more and more marked in the later Devonic and Carbonic. *Chonostrophia* is introduced in the Helderbergian and is continued into the Middle Devonic. *Stropheodonta* and *Strophonella*, which are represented by few and generally small species in the Siluric, are here present in great force and large size, recalling strongly the Middle Devonic. As to size and abundance, the same is true of the Rhynchonellas, while *Lissopleura* and *Eatonia* are unknown in the Siluric. *Gypidula galeata* and *Anastrophia verneuili* are good Siluric stragglers, but also denote a younger age in their greater size. The Spirifers, while indicating the Siluric, point without exception to post-Siluric age in their larger size and abundance; a characteristic Devonic aspect not being attained before the later Oriskany. The Retzias betoken post-Siluric age in their size and greater specific differentiation, while the finely plicated form of Middle Devonic time has here its first appearance in *Parazyga*. *Meristella* is unknown in the Siluric, but in the Helderbergian there is an abundance of this genus, and some of the forms have almost specific identities in the Middle Devonic. However, the most decided Devonic brachiopod facies is in the loop-bearing genera *Rensselæria*, *Trigeria*, and *Cryptonella*. Not one of the Terebratulacea is known in the Siluric, while in the upper portion of the Lower Devonic, both in America and Europe, the genera *Rensselæria*, *Meganteris*, and *Trigeria* have a size rarely attained by any subsequent terebratuloids.

On the other hand, of the characteristic Siluric trimerelloids of the genera *Dinobolus*, *Rhinobolus*, *Monomorella*, and *Trimerella*, not one is present. Of the strophomenoids, *Plectambonites*, *Streptis*, *Mimulus*, and

Triplecia; of the orthoids, *Platystrophia;* of the pentameroids, *Capellinia*, *Pentamerus*, and *Conchidium;* of the spire-bearing families, *Meristina*, *Whitfieldella*, *Hyattella*, *Clintonella*, *Hindella*, and *Homœospira*—and *Eichwaldia* or *Dictyonella*, *Parastrophia*, and *Rhynchotreta* fail to have a single representative in the Helderbergian or any younger formation.

The gastropods of the Helderbergian undoubtedly indicate the Devonic, in the prolific development of the platyceroids of which there are about 38 species. They are very closely linked with the Oriskany forms. Even the Siluric genera *Strophostylus* and *Diaphorostoma* (= Platyostoma) show progression in their larger species.

The pelecypods are rather scarce, but the abundance of Aviculopectenidæ points rather to the Devonic because of their paucity in the Siluric. The Devonic genera *Actinopteria* and *Paracyclas* begin here. Other genera with undescribed species—*Grammysia*, *Goniophora*, *Orthonota*, *Nuculites*, and *Maminka*—are present. The specimens are in the Beecher collection in Yale University Museum.

In the abundance of fenestelloids and fistuliporoids, the Bryozoa are greater than in the Siluric, and more in harmony with the younger Devonic faunas.

The crinoids of the Helderbergian are often fragmentary and for that reason the following genera may be dropped from this review: *Aspidocrinus* may be based on roots, and probably also *Camarocrinus*, while *Brachiocrinus*, or rather *Herpetocrinus*, is only known from fragments. The other genera found here are *Homocrinus* and *Melocrinus*, ranging from the Siluric to Middle Devonic; *Mariacrinus*, *Cordylocrinus*, and *Marsupiocrinus*, found either in the Ordovicic or Siluric, and *Edriocrinus* in the Oriskany and Middle Devonic. Thus far the evidence points to a Siluric facies for the crinoids. However, the negative evidence—that is, the absence of characteristic Siluric genera—*Ichthyocrinus*, *Lecanocrinus*, *Macrostylocrinus*, *Glyptaster*, *Dimerocrinus*, *Lampterocrinus*, *Lyriocrinus*, *Eucalyptocrinus*, *Pisocrinus*, and *Stephanocrinus*—furnishes indications that the crinoid development of the Helderbergian is markedly varied, and not Siluric in character. Of these genera but two—*Lecanocrinus* and *Eucalyptocrinus*—recur in the Devonic of Germany, each with one species.

From the foregoing summary of the Helderbergian fauna it is evident that most of the characteristic Siluric genera of trilobites, brachiopods, and crinoids are there absent. This might be expected, for, as has been seen in the previous chapter, about 2 per cent of the Helderbergian fauna are derived from the Siluric. On the other hand, in some of the trilobites, Bryozoa, and pelecypods, many of the gastropods, but more particularly in the diversified brachiopods, are met organic groups, which in their culmination are characteristic of the Devonic. It can not be denied that the Helderbergian fauna has a Siluric facies, yet these types either have greater differentiation in species or the forms attain a larger size. The fact that 9 per cent of the Helderbergian fauna pass into a generally accepted Devonic horizon, the Oriskany, outweighs the evidence of a Siluric facies and specific derivatives. The writer therefore concludes that the Helderbergian has a fauna unlike the Siluric, but one in harmony with the Devonic and its position near the base of that system.

Neither of the Helderbergian zones can be regarded as the deeper water facies of the littoral Oriskany, not only because the fauna of the latter has a more decided Devonic aspect, but also for the fact that wherever the two formations are present the Oriskany always overlies the Helderbergian. As far as known, there is no interlamination, and in New York, where the stratification is simple, there is a regular sequence. Where the older Oriskany is absent there is a slight unconformity between the Helderberg and the later Oriskany. This unconformity becomes a decided one in going from eastern to central New York, because the later Oriskany gradually comes to overlie successively the various members of the Helderbergian and finally the Cayugan.

Table of the Helderbergian Fauna *

C = Coeymans limestone ; S = New Scotland beds ; B = Becrafts limestone.

Species with * are also in Siluric below.
Species with † are also in Oriskany above.

	New York.	Maryland and Virginia.	Illinois and Missouri.	Tennessee.	Indian Territory.	Maine and New Brunswick.	Gaspé and Nova Scotia.
Sponges, 6 species.							
Hindia fibrosa (Roemer). 10553, 17158, 26009, 27719	C S	x	....	x	x		
Lysactinella gebhardi Girty	S						
" *perelegans* Girty	S						
Receptaculites infundibuliformis (Eaton)	S						
" n. sp.	S						
Ischadites squamifer (Hall). 27720.	S	....	....	x			

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* Not including the Upper Arisaig, which is Siluric. Some of the Tennessee and Cumberland species are known from Hall's private collection. Numbers are of specimens in the United States National Museum.

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Cœlenterata, 30 species.							
Dictyonema crassum Girty	S						
" *splendens* Billings	....	....	....	....	....	....	x
Monograptus beecheri Girty	S						
Syringostroma centrotum Girty	C						
" *faveolatum* Girty	C						
" *microporum* Girty	C						
" *barretti* Girty	C						
" *consimile* Girty	C						
Clathrodictyon jewetti Girty	C						
Duncanella rudis Girty. 4229, 27738	S	....	....	x			
Streptelasma strictum Hall. 4129, 9168, 10555, 17160	S	x	...	x			
" *waynensis* Safford. 27735–27737	....	...	....	x	x		
†*Zaphrentis rœmeri* Edwards and Haime. 4236, 9202, 10556, 27734	S	x	....	x			
" *rugatula* Billings	....	...	....	....	...	....	x
Aulopora schoharie Hall. 26031	S						
" *tubula* Hall	S						
" *subtenuis* Hall	S						
" *elongata* Hall	S						
Favosites basalticus Billings	...	...	....	....	....	x	
*† " *gotlandicus* Billings	...	....	...	....	...	x	
" *helderbergiæ* Hall. 10554, 17159, 27726, 27727	S	x	...	x			
† " *conicus* Hall. 4040, 27722, 27723	S	x	...	x	x		
" *conradi* Girty	C						
Microplasma (?) n. sp.	...	x					
Alveolites explanatus Hall. 27733	C S						
Cladopora clarkei Girty	S						
" *halli* Girty	S						
**Halysites catenularia* Linné	...	....	....	...	....	x	
Striatopora issa Hall. 27728, 27731	S	...	....	x			
" *missouriensis* Meek and Worthen	..	....	x				
Pleurodictyum lenticulare (Hall). 27732	S	...	....	x			
Echinodermata, 23 species.							
* *Homocrinus scoparius* Hall. 9113	C						
Melocrinus nobillisimus (Hall). 4151, 4866	C						
" *pachydactylus* Hall. 4811	C						
" *paucidactylus* Hall	C						
Corymbocrinus (?) *macropetalus* (Hall)	B						
Mariacrinus plumosus Hall	C						
" *stoloniferus* Hall. (Columns)	S						
" *ramosus* Hall	C						
Cordylocrinus plumosus (Hall)	C						
" (?) *ramulosus* Hall	C						
Marsupiocrinus tentaculatus (Hall)	S						
Herpetocrinus nodosarius (Hall)	S						
Edriocrinus pocilliformis Hall. 10558	S	x	x	x			

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Aspidocrinus scutelliformis Hall. 10559	S B						
“ *callosus* Hall	S						
“ *digitatus* Hall.	S						
Hadrocrinus polydactylus (Hall)	S						
Camarocrinus saffordi Hall. 27760	...	...	....	x			
Lepadocrinus gebhardi (Conrad). 10557, 26023	C	x					
“ n. sp. (Beecher collection)	C						
Sphærocystites multifasciatus Hall	...	x					
Anomalocystites cornutus Hall. (May be crustacean).	C						
Protaster forbesi Hall	C						
Annelida, 5 species.							
* *Spirorbis laxus* Hall. 27847	....	....	....	x			
Cornulites chrysalis Hall	S						
“ *cingulatus* Hall.	S						
Arabellites 2 n. sp. (Beecher collection)	S						
Bryozoa, 89 species.							
Vermipora serpuloides Hall	S			Tennessee Bryozoa unstudied.			
“ *robusta* Hall.	S						
“ (?) *tortuosa* Hall	S						
Hederella n. sp. (Beecher collection)	S						
Chætetes sphæricus Hall	S						
“ *proximus* Hall	S						
Monotrypa colliculatus Hall	S						
“ *helderbergiæ* Hall	S						
“ *monticulatus* Hall	S						
Monotrypella arbuscula Hall	S						
“ *abruptus* Hall	S						
“ *densa* Hall	S						
Trematopora (?) *corticosa* Hall	S						
Rhombopora regularis (Hall)	S						
“ *ovatipora* (Hall)	S						
“ *canaliculata* (Hall)	S						
“ *rhombifera* (Hall)	S						
“ *parallela* (Hall)	S						
Diamesopora constricta Hall	S						
“ *dispersa* Hall	S						
Callopora oppleta Hall.	S						
“ *cellulosa* Hall	S						
“ *perelegans* Hall	S	...	...	....	x		
“ (*Callotrypa*) *macropora* Hall	S						
“ “ var. *signata* Hall	S						
“ “ *heteropora* Hall	S						
“ “ *unispina* Hall	S						
“ “ *striata* Hall.	S						
“ “ *oculifera* Hall	S						
Chilotrypa venusta (Hall)	S						
“ *mediopora* Hall	S						

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Fistulipora ponderosa Hall	S			Tennessee Bryozoa unstudied.			
“ *parasitica* Hall	S	....	..	....	x		
“ *triloba* Hall	S						
Lichenalia crassa Hall	S						
“ *maculosa* Hall	S	....	...	....	?		
“ *torta* Hall	S						
“ *serialis* Hall and Simpson	S						
“ *distans* Hall	S						
Ceramopora maculata Hall	S						
“ *labeculoidea* Hall	S						
“ (?) *parvicella* Hall	S						
Paleschara incrustans Hall	S						
“ *radiata* Hall	S						
“ (?) *dissimilis* Hall	S						
“ *concentrica* Hall and Simpson	S						
“ (?) *bilateralis* Hall	S						
“ *tenuis* Hall and Simpson	S						
Stictopora papillosa Hall	S						
“ *obsoleta* Hall and Simpson	S						
“ *granatula* Hall and Simpson	S						
“ *granulosa* (Hall and Simpson)	S						
Ptilodictya lirata Hall	S						
“ *tenuis* Hall	S						
“ *nebulosa* Hall	S						
Thamniscus variolata Hall	S						
“ *fruticella* Hall	S						
“ (?) *cisseis* Hall	S						
“ (?) *nysa* Hall	S						
Fenestella crebripora Hall	S						
“ *junceus* Hall	S						
“ *cleia* Hall	S						
“ *hestia* Hall	S						
“ *æsyle* Hall	S						
“ *noe* Hall and Simpson	S						
“ *spio* Hall and Simpson	S						
“ *althæa* Hall	S						
“ *adraste* Hall	S						
“ *sylvia* Hall	S						
“ *philia* Hall	S						
“ *thyene* Hall; *F. coronis* Hall; *F. indalia* Hall	S						
“ *quadrula* Hall; *F. adornata* Hall and Simpson	S						
Unitrypa præcursor Hall; *U. nervia* Hall var. *constricta* Hall	S						
Hemitrypa biserialis Hall; *H. biserialis* var. *exilis* Hall and Simpson	S						
Polypora eudora Hall, *P. stricta* Hall and Simpson, *P. idothea* Hall, *P. compressa* Hall, *P. lilæa* Hall, *P. compacta* Hall, *P. arta* Hall, *P. obliqua* Hall and Simpson, *P. paxillata* Hall	S						
Ichthyorachis nereis Hall	S						

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Brachiopoda, 137 species.							
Lingula centrilineata Hall	S	x					
“ *perlata* Hall	C S						
“ *rectilatera* Hall	S						
“ *spathata* Hall	S						
“ *artemis* Billings							x
“ *lucretia* Billings							x
Orbiculoidea discus Hall. 17175	S B						
“ *conradi* (Hall)	S B						
“ n. sp. (Beecher collection)	S						
Schizocrania (?) *helderbergia* Hall	S	x					
“ *superincreta* Barrett	B						
Pholidops ovata Hall. 27763	S			x		x	
Crania agaricina Hall and Clarke	S			x		x	
“ *bella* Billings							x
“ *pulchella* Hall and Clarke. 27762	S			x			
† *Orthis* (*Rhipidomella*) *oblata* Hall. 4109, 10561, 10565, 17174, 26033, 27765–27768	S B	x	x	x	x	x	
† “ “ *oblata discus* (Hall)	S					x	
“ “ *oblata emarginata* (Hall). 7487, 27764, 27769		x		x	x		
“ “ *tubulostriata* Hall	S						
“ “ *eminens* Hall	S					x	
“ “ *assimilis* Hall. 8419, 26024	S B						
“ (*Dalmanella*) *subcarinata* Hall. 4114, 10566, 27773	S B		x	x	x		x
† “ “ *planiconvexa* (Hall)	S B	x		?			
“ “ *quadrans* (Hall)	S						
† “ “ *perelegans* Hall. 27770–27772	S B	x		x			
“ “ *concinna* Hall		x					
“ (*Schizophoria*) *multistriata* Hall. 10567, 26010 (Syn. *O. peduncularis* Hall)	S B						
“ (*Orthostrophia*) *strophomenoides* Hall. 10568, 27774	S			x	x	x	
“ (*Bilobites*) *varica* (Conrad). 4105, 8367, 9355, 10564, 27774	S			x	x	x	
Christiania subquadrata Hall and Clarke				x			
Leptænisca concava (Hall). 27780	S			x			
“ *adnascens* Hall and Clarke. 27779	S			x			
“ *tangens* Hall and Clarke	S						
* † *Leptæna rhomboidalis* (Wilckens). 3760, 4235, 8421, 9121, 9228, 14770, 10576, 17170, 26011, 27776–27778	C B	x	x	x	x	x	x
Strophomena (?) *elongata* Conrad	S						
† *Stropeodonta beckii* Hall. 10570, 17173, 27786, 27787	S B	x		x			
“ *perplana* (Conrad). 27788, 27789	B			?		?	
* “ *varistriata* (Conrad). 10547, 26047, 27790	C			x	x	x	x

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Stropeodonta arata Hall. 9172, 10573, 27791	S			x			x
" *indenta* (Conrad)	S					x	
" *planulata* Hall. 3888, 4038, 10571, 26034, 27785	C			x			
" (?) *conradi* (Hall). 10575, 27792, 27793	C			x			
Strophonella headleyana Hall. 17171, 17172	S						
" *geniculata* (Hall)		x					
" *punctulifera* (Conrad). 10572, 27781–27784 (Syn. *S. cavumbona* (Hall)	C B	x	x	x	x	x	x
" *leavenworthana* Hall. 10574	S B						
" (?) *radiata* (Vanuxem)	S	x					
† *Orthothetes woolworthianus* Hall. 9114, 10569, 27794, 27795	S			x			
" *deformis* Hall	S	x					
" *deformis sinuatus* Hall and Clarke		x					
* " *subplanus* (Conrad)	S						
Chonostrophia helderbergiæ Hall and Clarke	S						
† *Anoplia nucleata* Hall	S						
Chonetes punctata Simpson (Carbon county, Pennsylvania)	S						
" 2 n. sp. (Beecher collection)	S						
Scenidium insigne Hall	S			x			
Gypidula galeata (Dalman). 10494, 10611, 14771, 15965, 26026, 27796	C S	x		x	x	x	x
" *pseudogaleata* (Hall). 9181, 26019	B						
Anastrophia verneuili (Hall). 4115, 10601, 27797, 27798	S	x		x	x	x	
Rhynchonella semiplicata Conrad. 10597, 4232, 26012	C						
" *altiplicata* Hall	S	x					
" *aspasia* Billings						x	
" *acutiplicata* Hall. 27804	S				x		x
" *mainensis* Billings						x	
" *bialveata* Hall	S					x	
" *inutilis* Hall	S	?					
" *transversa* Hall. 27805, 27806	S	x		x			
" *rudis* Hall	S						
" *planiconvexa* Hall	S						
" *sulciplicata* Hall	S						
" *eminens* Hall	S						
Lissopleura æquivalvis (Hall). 4042	C	x					
Uncinulus mutabilis Hall. 4037, 10596, 15974, 26013	C	x					
" *nucleolatus* Hall. 4108, 4228, 9152, 27799, 27802	S			x	x	x	
" *abruptus* Hall. 27800	S	?		x			
" *pyramidatus* Hall. 4107, 10591	S				x		
" *vellicatus* Hall. 10593	S	?					
" *campbellanus* (Hall)	S B	x		x	x		
" *nobilis* Hall. 4220, 8414, 10595, 15975, 26025, 27801	B	x					

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Rhynchotrema formosum (Hall). 8415, 10594, 26017	S B	x					
Camarotœchia ventricosa Hall. 8416, 5059, 4106, 10592, 26044	B	x					
†*Eatonia medialis* (Vanuxem). 10598, 17168, 27089	S	x	....	x	....	x	
" *eminens* Hall	....	....	....	x			
" *singularis* (Vanuxem). 10599, 14773, 27807, 27808	S	x	....	x	....	....	x
† " *peculiaris* (Conrad)	S	....	....	x			
†*Spirifer cyclopterus* Hall. 4117, 10578, 27811–27815	S B	x	....	x	x	x	
" *concinnus* Hall. 3886, 10579, 26035, 27817, 27818	S B	x					
" (*Delthyris*) *perlamellosus* Hall. 8363, 9171, 10580, 17163, 26027, 27819–27821	C S	x	x	x	x	x	
" (*Delthyris*) *raricosta* (Conrad)	....	....	....	....	....	x	
" *macropleura* (Conrad). 3875, 10577, 17164, 27810	S	x	x	x	....	x	
" *saffordi* Hall	S	....	....	x			
" *tenuistriatus* Hall	....	....	....	x			
" *octocostatus* Hall. 27816	....	x	....	x			
†*Reticularia modesta* (Hall)	....	x	....	....	....	x	
" *nympha* (Billings)	....	....	....	....	....	x	
Cyrtina dalmani (Hall). 4140	S	....	x	x	....	x	
Trematospira perforata Hall	S	x					
" *dubia* (Billings)	....	....	....	....	....	x	
† " *multistriata* Hall. 10589	S	?					
" *equistriata* Hall and Clarke	....	x					
" *costata* Hall	S						
" *hippolyte* (Billings)	....	....	....	....	x	x	
" *simplex* Hall	....	....	....	x			
" *maria* (Billings)	....	....	....	....	....	x	
" *tennesseensis* Hall and Clarke	....	....	....	x			
Rhynchospira globosa Hall. 4138, 4225, 10586, 27829	S	x	....	x			
" *electra* (Billings)	....	....	....	....	....	x	
* " *formosa* Hall. 4135, 4224, 4226, 10489, 10585, 27827, 27828	S	x	....	x	x	x	
Parazyga deweyi Hall	S						
Nucleospira ventricosa Hall. 4147, 7488, 10584, 26029, 27831	S	x					
*† " *elegans* Hall	S						
" *concentrica* Hall	....	....	....	x			
*†*Atrypa reticularis* Linné. 4113, 4219, 8365, 8418, 10590, 26028, 26036, 27822–27824	C B	x	....	x	x	....	x
Anoplotheca concava (Hall). 4110, 17162, 17167, 10588, 26021, 27826, 27834	S	....	....	x	....	....	x
† " *flabellites* (Conrad)	....	x	....	....	....	....	x
" *subconcava* (Meek and Worthen)	....	....	x				
Atrypina imbricata Hall. 10587, 26020, 27825	S	....	x	x			
*†*Meristella lævis* (Vanuxem) ? 7490, 10583, 26040	C S	x	x	x	....	x	
" (?) *lævis* (Hall)	S	....	....	....	....	....	x
* " *bella* (Hall). 10582	S	....	....	....	....	x	

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Meristella (?) *blancha* (Billings)	....	....	...	....	...	x	
“ *subquadrata* Hall	C S						
† “ *arcuata* Hall. 17165, 27832	S	?	....	x	x	x	
“ var. *atoka* Girty	....	....	....	....	x		
“ *meeki* Hall. 3772	...	....	...	x			
† “ *princeps* Hall. 8420, 26016, 27837	S B	x	....	x		x	
Whitfieldella (?) *bisulcata* (Vanuxem)	C						
“ (?) *harpalyce* (Billings)	...	....	..	...	...	x	
Merista typus Hall	...	x					
“ *typus elongata* (Hall)	...	x					
“ *tennesseensis* Hall and Clarke. 27835	...	....	...	x			
Rensselæria mutabilis Hall. 26042, 27836, 27875	S	x					
“ *æquiradiata* (Conrad). 26022, 27837	B	....	....	....	x	....	x
“ *elliptica* Hall	S						
Trigeria (?) *portlandica* (Billings)	...	....	....	....	....	x	
Cryptonella (?) *eximia* Hall (New York ?)							
Pelecypoda, 48 species.							
Cypricardinia lamellosa Hall	S						
“ (?) *dorsata* Hall	S						
† “ (?) *sublamellosa* Hall	S						
“ (?) *concentrica* Hall	S						
“ *crassa* Hall	S						
Megambonia suborbicularis Hall	S						
“ *spinneri* Hall	C						
“ *rhomboidea* Hall	C						
“ *mytiloidea* Hall	S						
† “ *obscura* Hall	S						
“ *lata* Hall	S	....	....	....	x		
“ *oblonga* Hall	S						
“ n. sp. (Beecher collection)	S						
**Pterinea aviculoidea* Hall. 10604	C S						
Mytilarca cordiformis Hall	S						
Plethomytilus mytilimeris (Conrad). 10605	C S						
“ 2 n. sp.	S						
Avicula (?) *naviformis* Conrad. 26030	C	....	....	....	...	...	x
“ (?) *tenuilamellata* Hall	S						
“ (?) *subæquilatera* Hall	C						
“ (?) 2 n. sp. (Beecher collection)	S						
Aviculopecten spinulifera Hall	S						
“ *schohariæ* Hall	S						
“ *umbonata* Hall	C						
“ *manticula* (Conrad)	C						
“ *obliquata* (Hall)	C S						
“ *æquiradiata* (Hall)	S						
“ *communis* (Hall). 10603, 27838	S	...	....	x			
“ *pauciradiata* (Hall)	S						
“ *bellula* (Hall). 4810	S						

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Aviculopecten securiformis (Hall). 10602	S	..	...	..	x		
†*Actinopteria textilis* (Hall)	S						
Conocardium inceptum Hall. (Also Paleontology of New York, vol. v, part i.)	S						
" n. sp. (Beecher collection)	S						
Grammysia n. sp., *Goniophora* n. sp., *Paracyclas* n. sp., *Nucula* 3 n. sp., *Orthonota* n. sp., *Nuculites* n. sp., *Maminka* n. sp., *Modiolopsis* n. sp. (Beecher collection)	S						
Gastropoda, 54 species.							
**Holopea antiqua* (Vanuxem). 10625	B						
" *danai* Hall	C						
* " (?) *elongata* Hall	C						
Loxonema emaceratum Hall. (Syn. *L. attenuatum* Hall.)	S B	....	....	....	x		
" *fitchi* Hall	S B	....	....	....	....	?	
" (?) *obtusum* Hall	C						
" (?) *compactum* Hall. 4833, 10624	C						
" *planogyratum* Hall	C						
Murchisonia bilirata Hall	S						
†*Diaphorostoma ventricosa* (Conrad). 10621	S						
" *depressa* (Hall)	S						
" (?) *subangulata* (Hall)	S						
" *arenosa* (Conrad)	S						
Strophostylus elegans Hall	S						
" *globosus* Hall	S						
" *obtusus* Hall	B						
" *depressus* Hall	S						
" *fitchi* Hall	B						
" (?) *rotundatus* Hall	B						
†*Platyceras ventricosum* Conrad	S	....	....	....	....	x	
† " *gebhardi* Conrad. 10622	S B	....	....	....	x		
" *robustum* Hall	S						
" *sinuatum* Hall	S						
" *billingsi* Hall	S						
" *trilobatum* Hall. 4123, 10616	S						
" *unisulcatum* Hall	S						
" *tenuiliratum* Hall. 10613, 27844, 27845	S	....	....	x	x	x	
" *multisinuatum* Hall. 10614, 27843. (Syn. *P. bisinuatum* and *P. pentalobus* Hall.)	S						
" *retorsum* Hall. 10609, 10617	S B	....	....	....	....	x	
" *intermedium* Hall. 10611	S						
" *unguiforme* Hall. 10610, 25989, 27846. (Syn. *P. perplicatum* and *P. plicatile* Hall.)	S	....	....	x			
" *dilatatum* Hall. 4124, 10612. (Syn. *P. gibbosum* and *P. sulcoplicatum* Hall.)	S	....	....	....	....	x	

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Terr.	Me. and N. B.	Gaspé and N. S.
Platyceras platystoma Hall. 10615, 27991	S						
" *bisulcatum* Hall	S						
" *subundatum* Meek and Worthen			x				
" *pileiforme* Hall. 10619	S						
" *calantica* Hall. 8425, 10618	S						
" *obesum* Hall	S B						
" *lamellosum* Hall. 10607, 27842	S			x			
" *spirale* Hall. 10606. (Syn. *P. tubiforme* and *P. incile* Hall)	S	x	x				
" *newberryi* Hall	S						
" *plicatum* Conrad (Syn. *P. elongatum* Hall)	S						
" *pyramidatum* Hall	S		x				
" *arcuatum* Hall	S						
" *undulostriatum* Hall	S						
" *clavatum* Hall (Syn. *P. curvirostrum*, and *P. agreste* Hall)	B					x	
Hercynella perlata (Hall). 10620	S						
Pleurotomaria labrosa Hall	S B						
" n. sp	S						
Euomphalus decollatus Hall. 25990. (Syn. *E. disjunctus* Hall)	B						
" *sinuatus* Hall						?	
Bucania profunda (Vanuxem). 10626, 25987	B						
" n. sp. (Beecher collection)	S						
Bellerophon n. sp.	S						
Pteropoda, 6 species.							
Conularia pyramidalis Hall	S						
" *huntana* Hall	S						
Hyolithes centennialis Barrett	B						
" *heros* Hall	S						
" n. sp. (Beecher collection)	S						
† *Tentaculites elongatus* Hall. 10627, 17176, 26046	S B						
Cephalopoda, 10 species.							
Orthoceras longicameratum Hall. 25996	C	?					
" *rigidum* Hall. 25995	C					x	
" *subtextile* Hall	C						
" *desiderata* Hall (Syn. *O. clavatum* Hall)	C						
" *tenuiannulatum* Hall	S						
" *helderbergiæ* Hall	S						
" *perstriatum* Hall	S						
" *rude* Hall. 25997	S	x			x		
" *pauciseptum* Hall	S				x		
" n. sp. (Beecher collection)	S						

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Crustacea, 51 species.							
Primitia mundula var. Jones (cape Bon Ami)							
“ *æqualis* Jones and Hall (cape Bon Ami)							
Bythocypris oviformis Jones (DS. Penn.)							
Æchmina, 2 n. sp. (Beecher collection)	S						
Leperditia hudsonica Hall	S						
“ *subquadrata* Jones (DS. Penn.)							
“ *labrosa* Jones (cape Bon Ami)							
Beecherella carinata Ulrich	S						
“ *subtumida* Ulrich	S						
“ *subtumida intermedia* Ulrich	S						
“ *ovata* Ulrich	S						
“ *cristata* Ulrich	S						
“ *navicula* Ulrich	S						
“ *angularis* Ulrich	S						
Beyrichia granulata Hall	C						
“ *oculina* Hall	C						
“ *arcuata* (Bean) (cape Bon Ami)							
**Klœdenia acadica* (cape Bon Ami)							
* “ *notata* (Hall). 10551, 10552	S						
“ *notata ventricosa* Hall	S						
“ *pennsylvanica* Jones. (DS. Penn.)							
Bronteus barrandei Hall	C						
“ *pompilius* Billings	....	....	....	....	....	x	
“ *canadensis* Logan	....	....	....	....	....	....	x
Prœtus protuberans Hall. 4822	C	....	....	....	x		
“ *junius* Billings	....	....	....	....	....	x	
† *Homalonotus vanuxemi* Hall	S B						
Ceraurus tarquinius Billings	....	....	....	....	....	x	
Cordania cyclurus (Hall and Clarke)	S						
“ *macrobius* (Billings)	....	....	....	....	....	x	
Cyphaspis cœlebes Hall and Clarke	S						
“ n. sp. (Beecher collection)	S						
Phacops logani Hall. 10631, 14774, 27849	S	x	....	x	x	....	x
“ *traganus* Billings	....	....	....	....	....	x	
“ *hudsonicus* Hall. 27850, 27851	S	....	....	x	x		
†*Dalmanites* (*Odontochile*) *pleuroptyx* (Green). 4231, 5002, 5003, 4958, 10630, 14775, 25992, 25994	C B	x	....	....	x	....	x
“ (*O.*) *micrurus* (Green). 4946, 27852, 27853	C B	x	....	x			
“ (*Odontocephalus*) n. sp.	S						
“ (*Probolium*) *tridens* (Hall)	S						
“ “ *tridentiferus* (Shumard)	....	....	x				
“ “ *nasutus* (Conrad). 4150, 4803, 4934	S B						
“ (*Coryccphalus*) *dentatus* (Barrett)	S B						
“ *epicratis* Billings	....	....	....	....	....	x	
“ 2 n. sp. (Beecher collection)	S						

Table of the Helderbergian Fauna

	N. Y.	Md. and Va.	Ill. and Mo.	Tenn.	Ind. Ter.	Me. and N. B.	Gaspé and N. S.
Lichas (*Conolichas*) *bigsbyi* Hall. 4820	C S						
" " *pustulosus* Hall. 4861, 4950	S						
" (*Arges*) *consanguineus* Clarke	S						
†*Acidaspis tuberculata* (Conrad). 4949	S						
" (*Dicranurus*) *hamata* (Conrad)	S	....	x				
Lepidocoleus polypetalus Clarke	S						
	397	64	17	74	40	56	22

ORISKANIAN SUBDIVISIONS

Stratigraphic names applied to the Oriskanian.—The Oriskany formation was noticed by Eaton, who named it "Shell Grit." During the progress of the New York Geological Survey it was studied in detail, and was known as the "White sandstone," or the "Grey Brachiopodous sandstone." In 1839 Vanuxem gave it its present name from Oriskany falls. Clarke has called its fauna the "Hipparionyx Fauna," which practically comprises all that was known as the Oriskany prior to 1892. In Pennsylvania, the Oriskany is called division "Number 7;" in Maryland and Virginia, the "Monterey formation;" in northern Alabama, the "Frog Mountain sandstone;" in western Tennessee, "Camden chert;" and in southwestern Illinois, "Clear Creek limestone." In northeastern Canada the formation is present in divisions 7 and 8 of the "Gaspé limestone," and it may also continue into the lower portion of the "Gaspé sandstone." Possibly the formation has received other names, but no particular pains has been taken to collect them, since the first geographical name is the Oriskany of Vanuxem.

General character and distribution of the Oriskanian.—In a general way, it may be said that the Oriskany formation extends with many interruptions along the eastern and northern flanks of the Helderberg mountains of New York. Along the northern side, the Upper Oriskany only is known to be present, exceedingly variable in thickness, but never more than 30 feet, diminishing in volume and resting westwardly upon the successive lower horizons of the Helderbergian and finally on the Siluric. In the region of Cayuga lake it is sparingly present, and is practically absent west of Ontario county, the Corniferous or Onondaga then resting directly on the Salina or Waterlime. Beyond the Niagara river, to the northwest of Cayuga, in Ontario, the Oriskany reappears irregularly over a very limited area, again overlying the Salina, and is from 6 to 25 feet thick. Southerly, along the western side of the Hudson river, the Upper Oriskany is very intermittent and often but 2 or 3 feet thick. On Becraft mountain there is an outlier of Oriskany. In Orange county, the Oriskany again appears to thicken, and in the Neversink valley the thickness is about 125 feet, and at this point it is intimately connected with the Helderbergian. In New Jersey, and particularly in the eastern Appalachian folds of Pennsylvania, the Oriskany in its lithologic character is ever changing from sandy shales, sandstones, and chert beds to coarse conglomerates. Its thickness also increases from north to south; in northeastern Pennsylvania it is from 50 to 125 feet thick, and on the Lehigh river, below Bowmans, it is fully 200 feet. Continuing southwesterly with the Appalachian folds, coarse grained sandstones predominate. In the region about Cumberland, Maryland, the Oriskany is said to be 300 feet thick, but probably is much thicker. It is well developed in the vicinity of Monterey, Virginia, but southwesterly, near the state line of Tennessee, the thickness has decreased to 40 feet. Throughout the Appalachian region, from New York to Virginia, it follows upon the Helderbergian, but near the Tennessee state line it begins to rest on the Clinton.

In eastern Tennessee no Oriskany is known, yet it reappears as a sandstone with chert beds of about 20 feet thickness in the adjoining counties of Floyd, Georgia, and Cherokee, Alabama. The Oriskany here unconformably overlies horizons from the Middle Cambric to the top of the Champlainic or Ordovicic.

In southwestern Illinois cherty limestones of about 200 feet thickness, followed by a sandstone from 40 to 60 feet in depth, constitute the Oriskany formation, which is here, as in southeastern New York, intimately connected with the Helderbergian. The Oriskany of Illinois is known along the Mississippi river in three counties, and again appears in western Tennessee as a white chert horizon of about 60 feet thickness. It thus thins out rapidly toward Tennessee, and only the Lower Oriskany persists there with Helderbergian shales and limestones. Elsewhere in the United States the Oriskany is unknown, although the Helderbergian is well developed in Indian Territory.

In eastern Canada there are two areas of Oriskany outcrops; typically in the region about Cayuga, Ontario, as previously mentioned, the other area being in New Brunswick, on Campbell river, about Gaspé, Quebec, and about Nictou, Nova Scotia. In Gaspé, it is a limestone formation, and, as in New York and Illinois, is intimately connected with the

Helderbergian. In thickness it is not less than 800 feet, and as a few of the typical Oriskany species continue into the sandstones above, prove that some of this depth is to be included with the Oriskany or with the Esopus grit, of which fauna in the typical area, New York, practically nothing is known.

The detailed distribution, lithologic character, thickness, and local faunæ are given in full further on (see pages 300–331).

Oriskanian fauna.—As a rule the Oriskany formation consists of littoral deposits, often of a very coarse nature. When it is remembered that, in addition to this fact, the formation has very limited, usually linear exposures, it is remarkable that its fauna should consist of 185 species. Chief among these are the brachiopods, of which 97 species are known. They are the most abundant fossils, and their generally larger growth at once marks the Oriskany as one of the easily recognized American Paleozoic faunas.

In spite of the characteristic expression of the Oriskany fauna, it is remarkable that it should be so intimately connected both with the Helderbergian and with the Onondaga. Its affinities with the former are, of course, due to the recent discovery of a lower Oriskany fauna. Of the 185 species included in the Oriskany fauna, 31, or 17 per cent, come from the Helderbergian, while 54, or 35 per cent, pass into the Onondaga. Of the Helderbergian species, 24 pass into the Lower Oriskany, 17 into the Upper Oriskany, and 5 through both into the Onondaga. The last are *Favosites conicus*, *F. gotlandicus*, *Leptæna rhomboidalis*, *Atrypa reticularis*, and *Dalmanites pleuroptyx*. The Lower and Upper Oriskany zones have 43 species in common, or a little more than 23 per cent. These figures prove that the Oriskany is intimately connected with the Helderbergian and Onondaga. This is still more forcibly brought out when it is stated that of the Becraft fauna, the one immediately beneath the Oriskany, not less than 27 per cent of its species pass into the Oriskany.* All these figures are in strong contrast with the very few species which pass from the Niagaran and Cayugan formations into the Helderbergian. Of these there are 9 persisting forms, or about 2 per cent, in a fauna of 459 described species.

The Lower Oriskany of New York, Illinois, and Tennessee, probably represents a fauna practically of one zone. The Upper Oriskany, however, seems to have three overlapping stages. The New York Hipparionyx fauna apparently holds a central position; that of Cumberland is older, in part at least; while the Cayuga, Ontario, zone is certainly the youngest. In the beds of the latter region occur most of the Middle Devonic species, and here the Oriskany is directly overlain by the Onondaga limestone. In New York the Esopus intervenes between the Oriskany and Onondaga or Schoharie, and the time interval thus indicated may be occupied in the Cayuga region by the Oriskany.

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* Doctor John M. Clarke writes that the lowest Lower Oriskany beds of Becraft mountain have "a recurrent shaly limestone fauna," after which the true Lower Oriskany fauna makes its appearance. It is therefore probable that the percentage here given will be reduced, since the list beyond includes these beds in the Lower Oriskany.

The conspicuous Devonic character of this fauna is the presence of *Cystiphyllum*, *Heliophyllum*, and *Phillipsastrea* among the corals; *Stropheodonta*, *Hipparionyx*, *Pentamerella*, *Amphigenia*, *Spirifers* with long hinges and one with plicated fold and sinus, *Ambocœlia*, *Pentagonia*, and particularly *Rensselæria*, *Megalanteris*, and *Centronella* among the Brachiopoda; *Actinopteria*, *Palæopinna*, and *Mytilarca* among the Pelecypoda; an abundance of large platyceroids among the Gastropoda; and of the trilobites *Phacops*, *Dalmanites* (*Odontocheile*), and *Dalmanites* (*Chasmops*).

Table of the Oriskanian Fauna

(Named species only. For local distribution, see pages 300–331.)

	Helderbergian.	Lower Oriskany.	Upper Oriskany.	Onondaga.
Corals, 10 species.				
Zaphrentis incondita Billings			x	
“ *cingulosa* Billings			x	
“ *rœmeri* Hall	x	?		
Cystiphyllum sulcatum Billings			x	x
Heliophyllum exiguum Billings			x	x
Favosites hemisphericus Troost			x	x
“ *conicus* Hall	x	x	x	x
“ *gotlandicus* Lamarck	x		x	x
“ *turbinatus* Billings			x	x
Phillipsastrea affinis Billings			x	
Echinodermata, 7 species.				
Anomalocystites disparilis Hall			x	
Edriocrinus sacculus Hall		x	x	
Homocrinus proboscidalis Hall			x	
Technocrinus andrewsi Hall			x	
“ *sculptus* Hall			x	
“ *spinulosus* Hall			x	
“ *striatus* Hall			x	

Table of the Oriskanian Fauna

	Helderbergian.	Lower Oriskany.	Upper Oriskany.	Onondaga.
Bryozoa, 4 species.				
Cystodictya (?) *tarda* (Billings)			x	
Fenestella celsipora Hall		x		x
Polypora hexagonalis Hall			x	x
“ (?) *psyche* Billings			x	
Brachiopoda, 97 species.				
Orbiculoidea ampla Hall			x	x
“ *jervensis* (Barrett)		x		
Pholidops terminalis Hall		x	x	
Orthis (*Rhipidomella*) *musculosa* Hall			x	
“ “ *oblata* Hall	x			
“ “ *cumberlandia* Hall			x	
“ “ *livia* (Billings)			x	x
“ (*Dalmanella*) *perelegans* Hall	x	x		
“ “ *planiconvexa* Hall	x		x	
“ ? *lucia* Billings			x	
“ (?) *aurelia* Billings			x	
Leptæna rhomboidalis Wilckens	x	x	x	x
“ *rhomboidalis ventricosa* Hall			x	
Stropheodonta lincklæni Hall		x	x	
“ *becki* Hall	x	x		
“ *magnifica* Hall		x	x	
“ *perplana* Conrad		x	x	x
“ *magniventer* Hall			x	
“ *galatea* Billings			x	
“ *vascularia* Hall			x	
“ *irene* Billings			x	
“ *inæquiradiata* (Conrad),			x	x
“ *demissa* (Conrad) var			x	x
“ *hemispherica* Hall			x	x
Strophonella headleyana Hall	x	?	x	
“ *ampla* Hall			x	x
Orthothetes woolworthana Hall	x	x		
“ *pandora* (Billings)			x	x
Hipparionyx proximus Vanuxem		x	x	x
Pentamerella arata (Conrad)			x	x
Amphigenia elongata (Vanuxem)			x	x
Anoplia nucleata Hall		x	x	x
Chonetes hemisphericus Hall			x	x
“ *melonicus* Billings		x	x	
“ *mucronatus* Hall		?	x	x
Chonostrophia complanata Hall			x	
“ *reversa* (Whitfield)		x		x
Camarotœchia barrandei Hall		x	x	
“ *speciosa* Hall		?	x	
“ *pleiopleura* Hall		x	x	

Table of the Oriskanian Fauna

	Helderbergian.	Lower Oriskany.	Upper Oriskany.	Onondaga.
Camarotœchia pleiopleura fitchiana Hall			x	
“ *tethes* Billings		?		x
“ *billingsi* Hall			x	x
Rhynchonella excellens Billings			x	
“ *dryope* Billings			x	
“ *ramsayi* Hall			x	
Eatonia sinuata Hall			x	
“ *peculiaris* (Conrad)	x	x	x	
“ *medialis* Hall	x	x		
“ *pumila* Hall			x	
“ *whitfieldi* Hall			x	
Atrypa reticularis Linné	x	x	x	x
Anoplotheca dichotoma (Hall)			x	
“ *fimbriata* (Hall)			x	
“ *flabellites* (Hall)		x	x	x
“ *acutiplicata* (Hall)		x		x
Cyrtina rostrata Hall		x	x	
“ *dalmani* Hall	x	?		
“ *affinis* Billings		x	x	
Spirifer arenosus (Conrad)		x	x	x
“ *murchisoni* Castelnau	?		x	
“ *intermedius* Hall			x	
“ *tribulis* Hall		x	x	?
“ *cumberlandiæ* Hall			x	
“ *worthenanus* Schuchert		x		
“ *hemicyclus* Meek and Worthen		x		
“ *cycloptera* Hall	x	x	x	
“ *superba* Billings			x	
“ (*Delthyris*) *raricostus* Conrad			x	x
Reticularia fimbriata (Conrad)		x	x	
“ *modesta* (Hall)	x	x		
Metaplasia pyxidata Hall		x	x	x
Ambocœlia umbonata (Conrad)			x	
Meristella lævis Hall	x	x		
“ *lenta* Hall		x	x	x
“ *scitula* Hall			x	x
“ *lata* Hall		x	x	
“ *arcuata* Hall	x		x	
“ *walcotti* Hall and Clarke			x	
“ *princeps* Hall	x		?	
Pentagonia unisulcata (Conrad)			x	
Nucleospira elegans Hall	x		x	
Rhynchospira rectirostris Hall			x	
Trematospira multistriata Hall	x	x		
Rensselæria cumberlandiæ Hall			x	
“ *intermedia* Hall			x	
“ *marylandica* Hall			x	
“ *cayuga* Hall and Clarke			x	
“ *ovoides* (Eaton)		x	x	

Table of the Oriskanian Fauna

	Helderbergian.	Lower Oriskany.	Upper Oriskany.	Onondaga.
Beechia suessana Hall		?	x	
Oriskania navicella Hall and Clarke		x		
Megalanteris ovalis Hall		x	x	
Centronella glansfagea Hall			x	x
" *tumida* Billings			x	x
" *alveata* Hall			x	x
Pelecypoda, 23 species.				
Megambonia obscura Hall	x	x		
Aviculopecten gebhardi (Conrad)			x	
" *recticosta* (Hall)			x	
Actinopteria textilis Hall	x	?		
" *textilis arenaria* (Hall)		?	x	
Megambonia bellistriata Hall		x	x	
" *lamellosa* Hall		?	x	
Palæopinna flabellum Hall			x	
Pterinea flabellum (Conrad)			?	x
Cypricardinia planulata (Conrad)			x	
" *indenta* (Conrad)			x	x
Cypricardinia sublamellosa Hall?	x	?		
" *distincta* Billings			x	
Sanguinolites tethys Billings			x	
Goniophora mediocris Billings			x	
Mytilarca canadensis Billings			x	
" *nitida* Billings			x	
Leptodomus canadensis Billings			x	
" *percingulatus* Billings			x	
" *mainensis* Billings			x	
" *pembrokensis* Billings			x	
Anodontopsis ventricosa Billings			x	
Conocardium trigonale (Phillips)			x	x
Gastropoda, 28 species.				
Bellerophon plenus Billings			x	
" *curvilineatus* Conrad			x	x
Platyceras nodosum (Conrad)		x	x	
" *callosum* Hall			x	
" *subnodosum* Hall			x	
" *gebhardi* Conrad	x	x	x	
" *tortuosum* Hall		x	x	
" *magnificum* Hall		?	x	
" *patulum* Hall			x	
" *reflexum* Hall			x	
" *ventricosum* Conrad			x	
" *carinatum* Hall			x	x
" *concavum* Hall			x	x
" *dentalium* Hall			x	x

Table of the Oriskanian Fauna

	Helderbergian.	Lower Oriskany.	Upper Oriskany.	Onondaga.
Diaphorostoma affinis (Billings)	....	....	x	
“ *ventricosa* (Conrad)	x	x	x	
“ *turbinata* (Hall)	....	x	...	x
Strophostylus matheri Hall	....	....	x	
“ *transversus* Hall	....	....	x	
“ (?) *cancellatus* Meek and Worthen	....	x	....	
“ *expansus* Hall	....	x	x	
“ *andrewsi* Hall	....	....	x	
Cyrtolites (?) *expansus* Hall	....	x	x	
Murchisonia hebe Billings	....	....	x	
Loxonema subattenuata Hall	....	....	?	x
Pleurotomaria voltumna Billings	....	....	x	
“ *delia* Billings	....	....	x	
“ *lydia* Billings	....	....	x	
Pteropoda, 4 species.				
Conularia lata Hall	....	....	x	
Tentaculites elongatus Hall	x	x	x	
“ *arenosus* Hall	....	....	x	
“ *acula* Hall	....	x	x	
Cephalopoda, 1 species.				
Orthoceras arenosum Hall	....	....	x	
Crustacea, 11 species.				
Homalonotus major Whitfield	....	....	x	
“ *vanuxemi* Hall	x	....	x	
Phacops cristata Hall	....	x	x	x
“ *cristata pipa* Hall	....	....	x	x
“ (*Acaste*) *anceps* Clarke	....	?	....	x
Dalmanites phacoptyx Hall	....	x	....	x
“ (*Chasmops*) *anchiops* (Green)	....	....	x	x
“ (*Odontocheile*) *pleuroptyx* (Green)	x	....	x	x
Prœtus crassimarginatus Hall	....	....	x	x
“ *phocion* Billings	....	....	x	
Acidaspis tuberculatus Conrad	x	x		
	31	72	158	54

Table of European and American Lower and Middle Devonic Formations *

			North America.	Bohemia.	Rhineland.	Eifel.	Harz.	France (Loire).	England.
Devonic.	Neodevonic.	Chautauquan.	Chemung beds (Catskill sandstone, local facies).	(Étages G_2 to H_2 on the authority of Kayser and Holzappel. See Jahrb. k. k. geol. Reichsanstalt, 44, 1894, p. 514.)					
		Senecan.	Portage beds (Naples beds, Ithaca beds, Oneonta beds, local facies). Genesee shale. Tully limestone.						
	Mesodevonic.	Erian.	Stringocephalus beds of British America. Hamilton beds. Marcellus shale.	Étage H_2. Étage H_1.	Stringocephalus beds.	Upper Stringocephalus beds. Lower Stringocephalus beds.			Stringocephalus beds.
		Ulsterian.	Onondaga limestone. Schoharie grit. Esopus grit.	Étage G_3. Étage G_2. Étage G_1. Étage F_2 (Menian).	Calceola beds and Upper Coblenzian. ? Lower Coblenzian.	Calceola beds. Spirifer cultrijugatus beds.	Upper Coblenzian (Kayser and Holzappel).		Upper Coblenzian of Torquay (Kayser). Lower Coblenzian of Torquay (Kayser).
	Paleodevonic.	Oriskanian.	Upper Oriskany. Lower Oriskany.	A possible hiatus here.	Siegen.		Hercyn.	Erbray.	Looe beds, Cornwall (Kayser). Foreland grits (Frech).
		Helderbergian.	Kingston beds. Becraft limestone. New Scotland beds. Coeymans limestone.	Étage F_2 (Konieprussian). Étage F_1.	? Gedinnian. ? Taunus.				
Siluric.			Manlius or Rondout limestone.	Étage E.					Tilestones.

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* The terminology for North America is that of Clarke and Schuchert. Science, n. s., x, December 15, 1899, p. 876.

SUMMARY

In pages 245–252 it was shown that the upper limit of Murchison's Upper Silurian has been and still is vague, because the normal marine fauna gradually succumbed to local conditions, associated with the production of red sediments. In England and in the United States the eurypterids are the prevailing or characterizing fossils of these landlocked waters. Since the Tilestones and Downtonian of Great Britain are approximately synchronous with the Cayugan group of America, it is convenient to use both as the terminating strata of the Siluric system. Stability in taxonomy has for its basis original definition and priority in publication. This rule will not permit of the Siluric being extended to include the Helderbergian, which contains a fauna having almost nothing in common with this system in the typical area.

The Helderbergian sea transgressed widely over the land areas. Earth oscillations appear to be gentle throughout Lower and Middle Devonic times in eastern North America, the general tendency, however, being one of transgression, culminating in a continuously sinking sea bottom in the northeastern Mississippian sea during Upper Devonic time.

The Siluric system of America has three subdivisions—the *Oswegan, Niagaran, and Cayugan.* These correspond to the English Llandovery, or Valentian; Wenlock, or Salopian; and Ludlow, or Downtonian. The English and American Siluric horizons have much in common, as may be seen by the table on page 251.

In pages 252–268 the Old Red Sandstone and the original Devonian of Murchison and Sedgwick are described. The lower limits of the Devonic system, and particularly a lowest Lower Devonic fauna, have not been indicated by Murchison. By general consent, the stratigraphy and paleontology of the Devonic system have been determined in central Europe, and especially for the Lower Devonic in the Rhineland.

Since de Verneuil's visit to America (1847), the Oriskany formation has been generally accepted as the base of the Devonic in this country. It has its equivalents in the Rhineland in the Siegen grauwacke, or zone of *Spirifer primævus.* Similar horizons appear in part in the Lower Wieder Schiefer of the Hartz, in the hamlet of Erbray in the lower Loire, France; at Looe, in Cornwall, England, and possibly in the Lynton slates of North Devon.

All the foregoing European localities are of accepted Lower Devonic age. In Rhineland beneath the Siegen grauwacke are great masses of other Lower Devonic rocks, but their faunas do not readily correlate with American horizons. While part of the fauna of the Lower Wieder

Schiefer of Erbray, and of the Rhine Gedinnian, have aspects recalling the Helderbergian, no well established equivalent for the latter is known except that of the Bohemian étage F_2, or Konieprussian.

Barrande's étages F, G, and H, together with the Lower and Upper Helderberg, were regarded by him as members of the Upper Silurian. This interpretation is explained by the fact that Barrande included his first, second, and third faunas (now Cambric, Champlainic or Ordovicic, and Siluric) in one system, which he preferred to name the Silurian system. In his day, the well known Devonic faunas of the typical areas were those now classed as Middle Devonic. After much work and discussion, particularly in Germany, the opinion has now become general that all Barrande's étages F, G, and H are of Devonic age. As the Helderbergian is the equivalent of étage F_2, or Konieprussian, it must also be regarded as of Devonic, Lower Devonic, age.

The Upper Coblenzian fauna of the Rhine correlates readily with that of the Onondaga and Hamilton. As the latter faunas are intimately related and the Hamilton is always regarded as of Middle Devonic age, it seems natural to draw the line between the Lower and Middle Devonic, at the base of the Esopus grit and Upper Coblenzian. Both these formations are usually referred to the Lower Devonic. In United States the most marked local break in the Devonic exists between the Oriskany and Onondaga, and it is not closed by the very local Esopus and Schoharie grit. In a general view this break is not so apparent, owing to the varying age of the upper limit of the Oriskany in the various localities.

Page 269 begins with a short description of the three zones of the Helderbergian, and their geographical distribution. Then follows a discussion of the faunal characteristics, with a complete list of the species. The Helderbergian has 459 forms, of which about 2 per cent come from the Siluric, while 9 per cent of the former pass into the Oriskany. It is also shown that most of the characteristic Siluric genera of trilobites, brachiopods, and crinoids, fail in the Helderbergian; also that the Siluric facies maintained in this fauna is modified and the species have a larger individual growth, indicating post-Siluric age. On the other hand, among the trilobites, Bryozoa, and pelecypods, in many of the gastropods, but more particularly in the brachiopods, are met organic groups, which in their culmination are characteristic of the Devonic. The conclusion is therefore warranted that the Helderbergian fauna is unlike that of the Siluric, being more in harmony with the Devonic, and its position near the base of that system.

A general description of the Oriskany strata and its areal distribution follows, with a complete list of the named species. There are 185 forms, of which 17 per cent come from the Helderbergian and 35 per cent pass upward into the Onondaga or Corniferous. The Lower and Upper Oriskany may have a little more than 23 per cent of species in common, but this percentage will probably be modified when Doctor Clarke has finished his work on the Becraft Mountain fauna. These figures show conclusively that the Helderbergian, Oriskanian, and Onondagan are very intimately related; also the correctness of the conclusion of Sharpe and de Verneuil (1847), and later of all American geologists, that the Oriskany is Devonic.

In conclusion, the English, Continental, and American Lower and Middle Devonic horizons are tabulated on page 297.

Local Development and Faunas of the Oriskanian

UPPER ORISKANY OF NEW YORK

The Oriskany formation was first observed in New York, and for that matter in North America, by Professor Amos Eaton, who named it the "Shell Grit." Vanuxem, the state geologist of the third geological district of New York, appears to be the next to notice this formation, for in that district the Oriskany is well shown. In 1838 * he described it as the "White Sandstone.—Characterized by large species of Orthis [Hipparionyx] and Delthyris" [Spirifer]. In the following year Conrad † writes of it as the "Grey Brachiopodous sandstone" of the "Medial Silurian strata," characterized by *Atrypa elongata* (*Rensselæria ovoides* Eaton) and *Delthyris arenosa* (*Spirifer arenosus* Conrad).

In 1839, this formation received the name by which it has since been known. In that year Vanuxem ‡ stated that "the omission or absence of these two series to the west [Delthyris shale of the Lower Helderberg and the Cauda-galli] causes the next series of layers to repose immediately upon the Waterlime group. This is the white sandstone noticed on the hill at the falls of Oriskany, and for the present may be called the Oriskany sandstone. This sandstone is well known to extend over many of the states, occupying, like all geological masses, a fixed position in the whole series, but is exceedingly variable in thickness. According to the report of the state geologist of Pennsylvania, it is there 700 feet thick [this probably includes the Esopus grit; the Oriskany appears not to exceed 300 feet]. At Oriskany falls [it is] about 20 feet, on the road from Elbridge to Skaneateles, it is over 30 feet. At the quarries near Auburn, it is from a few inches to about 2½ feet; and at Split-Rock, near Syracuse, it shows itself in some parts by a mere sprinkling of sand, observable on the bottom of the layer which covers it, and in other parts by a thickness of about 6 inches. . . . The lower part of the sandstone abounds in fossil shells remarkable for their great size."

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* Second Ann. Rept. Geol. Survey, Third Dist. N. Y., 1838, p. 285.

† Second Ann. Rept. Pal. Dept., Survey N. Y., 1839, p. 62.

‡ Third Ann. Rept. Geol. Survey, Third Dist. N. Y., 1839, p. 273.

In 1840 Conrad* gave a section of the rocks as observed by him and John Gebhard, junior, the pioneer collector of Schoharie, New York, and places the Oriskany between the "Brown sandstone [Esopus grit] and Blue limestone" (Becraft of the Helderbergian). The fossils characterizing this zone are *Atrypa elongata* (= *Rensselæria ovoides* Eaton), *Delthyris arenosa* (= *Spirifer arenosa*), *and Strophomena unguiformis* (= *Hipparionyx proximus* Vanuxem).

In 1842 Vanuxem† gave what was known of the Oriskany formation in the third geological district of New York, and illustrated the characteristic fossils. These are *Spirifer arenosus* Conrad, *Rensselæria ovoides* (Eaton), *Eatonia peculiaris* (Conrad), and *Hipparionyx proximus* Vanuxem. He stated that—

> "This sandstone . . . is readily traced from east to west through the district, by its composition and its numerous characteristic fossils, not so much as to kinds as individual species. Its position is best seen in the first district near Salem; the Helderberg division, of which it forms a part, being complete. It projects from the side of the Helderberg mountain, forming a terrace resting upon the Catskill shaly limestone [= New Scotland; the Becraft is here absent]; . . . the sandstone passing under, or covered with the Cauda-galli grit, the latter being a thick abrupt mass.
>
> "In the third district, its immediate associates cease entirely before reaching the west end of Madison county; and the sandstone from thence rests upon the Manlius waterlime group, and is covered by the Onondaga limestone, the three rocks being coassociates to Cayuga lake. It is very variable in thickness, owing probably to the unevenness of the surface upon which it was deposited.
>
> "With some exceptions, this sandstone consists of a medium sized quartz sand. . . . It is of a light yellow color when pure, as at Oriskany Falls. At other localities the yellow color is often shaded brown, or of some other dark color."

West of the Hudson river, in eastern New York, the Oriskany—

> "Is well exposed in the hills east and west of Schoharie, various places on the Helderberg in Bern, Knox, and Bethlehem, and occasionally as it ranges southward to Esopus falls, beyond which it was not recognized. The Oriskany sandstone [in this region] is generally a hard silicious grit, which generally approaches chert and hornstone in aspect, and is replete with fossils. In some places it is white; in others brown, red, and black. . . . In the first district, it rarely exceeds 2 feet in thickness, and in many places it is not more than 8 inches, and in some places is absent; but it is extensive, strongly marked in its fossil contents, which are of large size, and generally attracts the attention of persons traveling along the roads."‡

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* Third Ann. Rept. Pal. Dept., Survey N. Y., 1840, p. 40.

† Geol. N. Y., part iii, Survey Third Dist., 1842, pp. 123-127.

‡ Geol. N. Y., part i, Survey First Dist., 1843, pp. 342, 343.

In the second district, Emmons did not observe this formation, and in the fourth district it is not well developed. Hall* writes that the Oriskany—

> "Where best developed in the fourth district, is a coarse, rather loosely cemented, purely silicious sandstone, of a yellowish white color. It contains some flattened nodules of chert or flint. . . . In the upper part of the rock are numerous concretions of dark colored or nearly black compact crystalline sandstone, very hard and tough. . . . In Monroe county, its only representative is a layer of greenish conglomerate, about 4 inches thick. . . . At one or two other points it appears as a coarse sandstone of a few inches in thickness, resting on the Onondaga salt group. The last place in the district where it has been noticed is in the bed of Black creek at Morganville, in Genesee county."

The Oriskany sandstone in New York "is not more than 30 feet, and usually much less."† This, of course, does not refer to southeastern New York, where this formation is much thicker.

The Oriskany formation is best developed in southeastern New York, in Orange county.

> "The western belt forms the western part of the Helderberg ridge, which extends up the Neversink valley from Pork Jervis, New York. It consists of fine-grained shaly sandstones and impure limestones, the latter often containing many fossils. . . . There are also present cherty bands containing fossils. The Oriskany forms narrow ridges, and the thickness of the formation is about 125 feet.
>
> "The second [or eastern] Oriskany area is along the western side of Bellvale and Skunnemunk mountains, where it affords a fine grained red or gray quartzite which changes locally to a conglomerate. . . . About 100 feet are exposed." ‡

Doctor S. T. Barrett, living for many years at Port Jervis, studied the outcrops and collected the faunas of the Niagaran, Helderbergian, and Oriskanian formations of this region. In 1876 § he published his results, and from these it is learned that the Upper Pentamerus or Becraft passes without break into the Oriskany. The Oriskany is here not less than 100 feet in thickness, while "it is probably more, the higher arenaceous layers of this division having been removed."

The fauna collected by Barrett from this horizon consists of the following:

Orbiculoidea jervensis (Barrett).
Eatonia peculiaris (Conrad).
Spirifer arenosus (Conrad).
Spirifer murchisoni Castelnau.
Rensselæria ovoides (Eaton).
Diaphorostoma ventricosa (Conrad).
Platyceras gebhardi (Hall).
Actinopteria textilis arenaria (Hall).
Tentaculites elongatus Hall.

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* Geol. N. Y., part iv, Survey Fourth Dist., 1843, pp. 146–150.

† Hall: Geol. N. Y., Survey Fourth Dist., 1843, p. 147.

‡ Heinrich Ries: Fifteenth Ann. Rept. State Geol. N. Y., 1897 [1898], p. 402.

§ Ann. Lyc. Nat. Hist. N. Y., vol. xi, 1876, pp. 293, 294.

It was not until 1859 that the Oriskany fauna became well known. In that year Hall, the state geologist of New York, published his epoch-making volume, "Palæontology III of the Natural History of New York, Part VI." Below is given a complete list of the known, typical, New York Oriskany fauna, the Upper Oriskany, or, as Clarke* has named it, the "Hipparionyx fauna." Regarding this fauna Hall † wrote:

> "The great changes in the physical conditions supervening at the close of the preceding group [Helderbergian] indicate an influence which would affect in an equal manner the fauna of the succeeding one, and we find accordingly few species passing from the Lower Helderberg group to the Oriskany sandstone. The changes, however, are mainly of a specific character; no new genera being introduced, so far as known, though some of them appear under modified forms."

After pointing out the characteristics of the Oriskany fauna, he concludes as follows:

> "It is not possible, therefore, to point out any changes in the fauna of this period sufficient to indicate the commencement of a new system, and its relations with the formations below are as intimate as with those above, while in the northern and middle states, the Oriskany sandstone bears in its fauna a closer relation to the lower than to the overlying formations."

In the Lower Oriskany fauna discovered by Beecher and worked out by Clarke, as described beyond, there is no appreciable break between the Becraft and the Oriskany, either in deposition or in the successive faunal links. Until very recently, but 14 forms were known to be common to the Helderbergian and Oriskanian, but there are now 31 (24 in New York) species.

FAUNA OF THE UPPER ORISKANY, OR HIPPARIONYX ZONE

Favosites hemisphericus Troost. Hall collection, Albany.
Pholidops arenaria Hall.
Orbiculoidea ampla Hall. 26054.
Chonostrophia complanata Hall. 28108, 10643.
Orthis (*Rhipidomella*) *musculosa* Hall. 4882.
Anoplia nucleata Hall. 10644.
Leptæna rhomboidalis ventricosa Hall. Hall collection, Albany.
Stropheodonta lincklæni Hall. 10640, 10641, 26056.
Stropheodonta (*Leptostrophia*) *magnifica* Hall. 4885, 5082.
Stropheodonta (*Leptostrophia*) *magniventer* Hall. 4805.
Stropheodonta vascularia Hall.
Hipparionyx proximus Vanuxem. 4217, 4227, 4809, 10638, 26060, 28107.
Camarotœchia barrandei Hall. 4816.

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* Amer. Jour. Sci., November, 1892, p. 411.

† Pal. N. Y., vol. iii, 1859, pp. 401- .

Camarotœchia pleiopleura Hall. 16680, 28095.
Syn. *Rhynchonella multistriata* and *R. oblata* Hall.
Camarotœchia pleiopleura fitchiana (Hall).
Camarotœchia principalis Hall (= *C. speciosa* Hall).
Camarotœchia septata Hall. Species of no value.
Eatonia peculiaris (Conrad). 10651, 26057.
Eatonia pumila Hall (= *E. whitfieldi*).
Eatonia whitfieldi Hall. 26058, 28089, 28090.
Spirifer arenosus (Conrad). 4121, 4214, 8412, 10645, 14515, 16680*b*, 26048, 28102.
Spirifer murchisoni Castelnau (= *S. arrectus* Hall). 8413, 10646, 16669, 26051, 28098.
Spirifer tribulis Hall. 10647.
Reticularia fimbriata (Conrad). Hall collection, Albany.
Metaplasia pyxidata Hall. 4215, 10648.
Cyrtina rostrata Hall.
Atrypa reticularis Linné. 28091.
Anoplotheca dichotoma (Hall). Hall collection, Albany.
Anoplotheca flabellites (Conrad). 10650.
Meristella lata Hall. 16680, 26053, 28113.
Meristella walcotti Hall and Clarke ?. 16672.
Pentagonia unisulcata (Conrad). Hall collection, Albany.
Megalanteris ovalis Hall. 26059.
Rensselæria ovoides (Eaton). 4118, 4216, 8428, 8430, 10652, 16671, 28087, 26049.
Beechia suessana Hall. 16680.
Tentaculites arenosus Hall.
Conularia lata Hall.
Bellerophon curvilineatus Conrad (also in Schoharie grit).
Platyceras nodosus Hall.
Platyceras (*Orthonychia*) *tortuosus* (Hall). 10655.
Platyceras n. sp. 28083.
Diaphorostoma ventricosa (Conrad). 4802, 26050, 28080, 28082.
Strophostylus expansus Hall.
Cyrtolites (?) *expansus* Hall. 10659.
Orthoceras arenosum Hall.
Aviculopecten gebhardi (Conrad). 10654.
Aviculopecten recticosta (Hall).
Actinopteria textilis arenaria (Hall).
Megambonia bellistriata Hall.
Megambonia lamellosa Hall. 26055.
Palæopinna flabellum Hall.
Homalonotus major Whitfield
Phacops cristata Hall. 28079.

LOWER ORISKANY OF NEW YORK

Previous to the year 1892, the known Oriskany formation in the state of New York consisted of but a thin sandstone horizon, nowhere known to exceed 30 feet in thickness. The specific faunal gap between it and the Helderbergian below was considerable; but in that year Doctor

Beecher discovered in so well known a region as Becraft mountain, east of the Hudson river, and just south of Hudson, New York, a new geological horizon and a fauna intimately connected with the Becraft of the Helderbergian below and the true, or Hipparionyx, Oriskany above.

Regarding this horizon, Doctor Beecher* writes:

> "In 1890 . . . in the Becraft's Mountain region of Columbia county, New York, a fauna was discovered by the writer, which in many respects is new to the State. Its affinities are with the Oriskany, but its geological position is below the true Oriskany sandstone. It appears to include a part, at least, of what has been referred to the Lower Helderberg group on account of its lithological characters and upon insufficient paleontological grounds. The fauna of the Upper Pentamerus in its original locality (Schoharie, New York) has previously been recognized to contain several species quite distinct from the Scutella, Shaly, and Lower Pentamerus limestones, which represent the typical Lower Helderberg group. Moreover, as the complete fauna has remained unknown and the series has been confused with the underlying Scutella limestone, no exact correlations have been made.
>
> "From the fossils now known from Becraft's mountain and several other localities, it is evident that the relations of the fauna contained in the upper beds of the series above the Scutella limestone and just below the Oriskany sandstone are with the latter, and not with the Lower Helderberg group. . . .
>
> "At Becraft's mountain the rock is a hard, cherty, arenaceous limestone, weathering into a rotten fine-grained sandstone [a few feet in thickness], preserving the molds of the fossils or their silicified replacements. . . . At Port Jervis, New York, it is in general still more calcareous, although there are some cherty layers, and many of the fossils are silicified. Here, too, the series is continuous from the Oriskany sandstone down through the trilobite beds of Mather, Horton, and Barrett. The arenaceous character of the beds gradually decreases downwards, carrying the typical Oriskany species into the *Dalmanites dentatus* layers and below, and making the whole series of this group at Port Jervis probably over two hundred feet in thickness, of which one hundred or more belong to the Lower Oriskany."

Barrett† gives the thickness of the Oriskany formation at Port Jervis, New York, as "100 feet; it is probably more, the higher arenaceous layers of the division having been removed by glacial action." Ries gives the thickness for the same region as "about 125 feet." The known Oriskany fauna from this region is meager, but for the present it is referred to the Upper Oriskany. The transition, however, from the Becraft limestone to the Oriskany in the Port Jervis region is apparently uninterrupted. Doctor Barrett writes:

> "From the top of Trilobite Ridge [his uppermost Upper Pentamerus bed, or 5c, with a thickness from 5 to 10 feet] to the foot of the Cauda-galli ridge, northwest of it, Oriskany fossils predominate. There is, however, such a gradual shading off from one into the other, that no one whose knowledge of the Lower Helderberg and Oriskany strata had been acquired by the study of their exposures in this

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* Amer. Jour. Sci., vol. xliv, 1892, pp. 410, 411.

† Ann. Lyc. Nat. Hist. N. Y., vol. xi, 1876, p. 294

locality would ever think of running the line separating the Silurian and Devonian ages, between the two. They seem so intimately blended that the exact line between them is an arbitrary one altogether."

If the fauna from "Trilobite ridge" or Barrett's zone "5c" or Beecher's "Dalmanites dentatus layers" is studied, it will be conceded that it is unmistakably that of the Becraft, and cannot be included in the Lower Oriskany, as is done by Beecher. The fauna as given by Barrett,* with a few additions by the present writer, is the following:

Orbiculoidea discus Hall, *O. conradi* (Hall), *Orthis* (*Dalmanella*) *perelegans* Hall, *O.* (*D.*) *planiconvexa* Hall, *O.* (*Rhipidomella*) *oblata* Hall, *O.* (*R.*) *subcarinata* Hall, *O.* (*Schizophoria*) *multistriata* Hall, *Leptæna rhomboidalis* Wilckens, *Stropheodonta becki* Hall, *S. perplana* Conrad, *Strophonella cavumbona* Hall, *S. leavenworthana* Hall, *Chonostrophia* n. sp., *Spirifer murchisoni* Castelnau, *S. concinnus* Hall, *S. cyclopterus* Hall, *Cyrtina rostrata* Hall, *Rensselæria æquiradiata* (Conrad), *Actinopteria textilis* Hall, *Platyceras retrorsum* Hall, *P. gebhardi* Hall, *Loxonema fitchi* Hall ?, *Holopea antiqua* (Vanuxem) ?, *Hyolithes centennialis* Barrett, *Dalmanites dentata* Barrett, *D. pleuroptyx* (Green), *D. nasutus* Conrad, *D. micrurus* (Green), and *Homalonotus vanuxemi* Hall.

Of this fauna with 29 species, all are Helderbergian forms with the exception of the following, which are Oriskany species: *Stropheodonta perplana*, *Spirifer murchisoni*, and *Cyrtina rostrata*. This evidence is very conclusive that the three zones of Barrett's Upper Pentamerus limestone are properly correlated.

The Becraft fauna was extensively collected by Clarke, Beecher, and the writer, but more particularly by the former, for the New York State collection. Doctor Clarke has published "A preliminary list of the species constituting the Oriskany fauna of Becraft's mountain, New York,"† which is given below, with a few alterations. Regarding this fauna, Doctor Clarke concludes that—

"This remarkable association of species furnishes the missing link in the evolution of the Lower Helderberg into the typical Lower Devonian fauna. While the presence of so many positive Oriskany types determines the faunal quantivalence, the perdurance of species and modifications of specific expressions characteristic of the shaly limestone fauna, and the inception of Lower Devonian specific forms, render this combination altogether unusual and of prime significance in the correlation of our earlier Devonian. The southwestern extension of the Oriskany (*Hipparionyx*) fauna, as in Maryland, is complicated with the Lower Helderberg, but to a less degree than here; while in the representative of the same fauna in the province of Ontario there is a great predominance of Upper Helderberg species. With the 46 species which have been identified in the Hipparionyx fauna of New York, the 106 or more species of the Becraft fauna are in striking contrast, and no element so strongly enforces this contrast or is so unique in itself as the *Crustacean.* The association is indubitably of early Oriskany age and is eminently the Trilobite or Dalmanites facies of the Oriskany fauna.''

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* Ann. Lyc. Nat. Hist. N. Y., vol. xi, 1876, p. 296, and Amer. Jour Sci., vol. xiii, 1877, p. 386.

† Amer. Jour. Sci., vol. xliv, 1892, pp. 411–414.

*FAUNAL LIST OF THE NEW YORK LOWER ORISKANY**

(Numbers indicate material in United States National Museum. Those species marked with an * are also in Ulsterian.)

	Also in Held.	Lower Oriskany, Becraft Mt.	Upper Oriskany.
Hindia sp.		x	
Edriocrinus sacculus Hall		x	
Zaphrentis cfr. *rœmeri* Hall		x	
“ sp.		x	
Romingeria sp.		x	
Trachypora sp.		x	
Monticulipora sp.		x	
Hederella sp.		x	
Clonopora sp.		x	
Reptaria sp.		x	
Polypora sp		x	
Hemitrypa cfr. *columellata* Hall		x	
* *Fenestella celsipora* Hall		x	
“ sp.		x	
Lingula sp		x	
Orbiculoidea sp		x	
Crania sp. 28008		x	
“ n. sp.		x	
Pholidops terminalis Hall. 28007		x	x
“ sp. n.		x	
Orthis (*Dalmanella*) *perelegans* Hall	x	x	x
“ (*Rhipidomella*) *oblata* Hall? 28009	x	x	x
Orthothetes cfr. *woolworthana* Hall		x	
“ n. sp. 28014		x	
Hipparionyx proximus Vanuxem		x	x
* *Leptæna rhomboidalis* Wilckens. 28013	x	x	x
Stropheodonta lincklæni Hall		x	x
“ cfr. *radiata*. 28016		x	
“ n. sp. A		x	
“ n. sp. B		x	
“ (*Leptostrophia*) *magnifica* Hall		x	x
“ “ *becki* Hall. 28015	x	x	
* “ “ *perplana* Conrad. 28012		x	
Strophonella headleyana Hall?	x	x	
Chonetes melonica Billings. 28018		x	x
Chonostrophia n. sp. 28019		x	
Anoplia nucleata Hall. 28017		x	x
Spirifer murchisoni Castlenau. 28020		x	x
* “ *arenosus* (Conrad). 28021		x	x

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*A monograph of this fauna, by Doctor J. M. Clarke, is now in preparation.

Faunal List of the New York Lower Oriskany

	Also in Held.	Lower Oriskany, Becraft Mt.	Upper Oriskany.
Reticularia modesta (Hall)	x	x	
* " *fimbriata* (Conrad)		x	x
**Metaplasia pyxidata* (Hall). 28022		x	x
Crytina rostrata Hall. 28023		x	x
" cfr. *dalmani* Hall		x	
Meristella lata Hall. 28024		x	x
" *lævis* Hall? 28026	x	x	
* " *lenta* Hall. 28025		x	x
" n. sp.		x	
Trematospira multistriata Hall	x	x	
Anoplotheca n. sp. 28028		x	
" sp		x	
* " *flabellites* (Hall). 28027		x	x
* " *acutiplicata* (Hall)		x	
Anastrophia n. sp.		x	
Rensselæria ovoides (Eaton). 28029		x	x
Megalanteris ovalis Hall?		x	x
Beachia suessana Hall?		x	x
Camarotœchia oblata Hall. 28011		x	x
" *barrandei* Hall		x	x
" *speciosa* (Hall)?		x	x
Rhynchonella sp		x	
Eatonia medialis Hall	x	x	
" *peculiaris* Conrad. 28010	x	x	x
Oriskania navicella Hall and Clarke		x	
Cryptonella n. sp.		x	
Actinopteria textilis Hall?	x	x	
Aviculopecten sp		x	
Megambonia bellistriata Hall. 28032		x	x
" *lamellosa* Hall?		x	x
Goniophora n. sp.		x	
Cypricardinia cfr. *sublamellosa* Hall. 28031	x	x	
Conocardium sp		x	
Platyceras (*Orthonychia*) *tortuosus* (Hall)		x	x
" *nodosum* (Conrad)		x	x
Strophostylus expansus (Conrad)		x	x
Diaphorostoma ventricosa (Conrad). 28034	x	x	x
" n. sp.		x	
Cyrtolites expansus Hall? 28033		x	x
Pleurotomaria n. sp.		x	
Bellerophon n. sp.?		x	
Conularia sp		x	
Coleolus sp.		x	
Leperditia sp.		x	
Primitia sp		x	
Dalmanites n. sp. A. 28035		x	
" n. sp. B.		x	
" n. sp. C.		x	
" sp		x	

Faunal List of the New York Lower Oriskany

	Also in Held.	Lower Oriskany, Becraft Mt.	Upper Oriskany.
* " *phacoptyx* Hall	......	x	
Phacops n. sp. 28036	......	x	
" (*Acaste*) cfr. *anceps* Clarke	......	x	
Homalonotus sp.	......	x	
Cordania n. sp	......	x	
Cyphaspis n. sp	......	x	
Proetus n. sp. ?	......	x	
" n. sp. B	......	x	
Acidaspis tuberculatus Conrad	x	x	
Turrilepas sp.	......	x	
Spirorbis sp	......	x	
Autodetus n. sp.	......	x	
Fish spine	......	x	
Tentaculites elongatus Hall. 28006	x	x	x
" *acula* Hall	x	x	
	14	104	31

Of this Lower Oriskany fauna of 104 species, 45 are specifically identified with described species, and of these no less than 35 occur above, either in the Upper Oriskany or Ulsterian, while 14 are present in the Helderbergian. Doctor Clarke's statement that "this remarkable association of species furnishes the missing link in the evolution of the Lower Helderberg into the typical Lower Devonian fauna," and Beecher's "from the fossils now known from Becraft's mountain, it is evident that the relations of the fauna contained in the upper beds of the series above the Scutella limestone and just below the [Upper] Oriskany sandstone are with the latter and not with the Lower Helderberg group" are just.

It is very desirable that collectors should give attention to gathering more extensive collections from the Upper Pentamerus or Becraft about Port Jervis and Schoharie, New York, and also from the Oriskany along the Neversink valley. Such collections will probably demonstrate the intimate relationship of the Becraft and Lower Oriskany formations.

PENNSYLVANIA AND NEW JERSEY ORISKANY

At present the Oriskany formation of Pennsylvania and New Jersey is not clearly divisible into a lower and upper member as in New York.

Along the Delaware river, this formation is very variable in its lithological characters, follows directly upon the Helderbergian series, and is overlain by a great mass of Esopus grit.

Lesley * summarizes the work of the "Second Geological Survey of Pennsylvania" on the Oriskany formation as follows:

> "In Pennsylvania the outcrops of Oriskany extend in straight and curved lines and many zigzags through nineteen counties, a total distance of 1,100 miles; the formation, however, appearing and disappearing, thickening and thinning; varying in character from sandy shales to massive flint rock; in some places crowded with shells, at others almost destitute of them; in some places calcareous, in others with scarcely a trace of lime, in some places highly ferruginous, even containing iron enough to furnish furnace ore."

The maximum thickness in Pennsylvania is probably not over 200 feet. It has been given as 700 feet, but this depth apparently includes either the Helderbergian or the Esopus grit.

The Oriskany and Helderbergian series, as exposed in the Neversink valley, enter New Jersey and Pennsylvania southwestward from Port Jervis, New York. The Oriskany of this region is described by I. C. White,† as follows:

> "The rocks which make up the Oriskany series change so radically in character in passing southwest from the eastern line of the district that there is scarcely anything in common to the sections of the group at the eastern line of Pike and the western line of Monroe.
>
> "The sandstone member of the series is entirely absent at the eastern extremity of Pike county, the only representative of the Oriskany there present being a bed of limy, cherty shales, weathering down into muddy looking beds holding Oriskany fossils. They are in fact a mere continuation of the Lower Helderberg beds up to the very base of the Cauda-galli grit."

At Carpenters Point village, the Oriskany was estimated as 50 feet thick. On crossing the Delaware river into Monroe county, the Oriskany appears to thicken and at Broadhead creek is 45 feet thick, at the western line of Monroe about 175 feet, and is fully 200 feet thick on the Lehigh river below Bowman's.

George H. Cook,‡ the state geologist of New Jersey, describes the Oriskany of that state as follows:

> "Under this division [Oriskany sandstone] we have included the large mass of rock lying between the Lower Helderberg and Cauda-galli. There is a thin bed of tender sandstone, or almost sand, full of indistinct marks of fossils, which may be considered as the base of the formation. It is hardly eight feet thick, and may

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* Second Geol. Survey Pa., Summary Final Report, vol. ii, 1892, pp. 1036, 1037.

† Second Geol. Survey Pa., vol. G6, 1882, pp. 122-126.

‡ Geol. of New Jersey, 1868, pp. 160, 161.

be seen above W. Nearpass' quarries; near Peters valley; at Walpeck Center, and west of Flatbrookville. Lying on this is a thick body of shale, which constitutes the principal part of the formation.

"The shale is light-colored, soft, and disintegrates easily. Some of the beds are very calcareous, while others are gritty. Fossils are quite abundant, especially in the upper layers, near the Cauda-galli grit.

"This formation may be seen almost everywhere, from the Stateline to Walpeck bend. . . . . A fine locality for examining rocks and included fossils is along Chamber's Mill brook, northwest of Isaac Bonnell's residence.

"As estimated, west of Flatbrookville the shaly rock is about 120 feet thick. From the breadth of the outcrop west of Walpeck Center, and with a uniform dip of 40 degrees to the northwest, its thickness would be made to be over 300 feet. The difficulty of always fixing the angle of the dip renders this examination a matter of uncertainty."

The Oriskany of New Jersey is intimately connected with that of New York and Pennsylvania, and the reader is referred to these sections of this paper for other details.

FAUNAL LISTS OF NEW JERSEY AND PENNSYLVANIA

At Carpenters Point, 4 miles southeast of Port Jervis, New York, in a lime shale with chert, I. C. White* found—

Tentaculites elongatus Hall.
Eatonia peculiaris (Conrad).
Spirifer murchisoni Castelnau.
Spirifer arenosus (Conrad).
Rensselæria ovoides (Eaton).
Actinopteria textilis arenaria (Hall).
Platyceras gebhardi Hall.
Platyceras ventricosum Conrad.

On Broadhead creek, near Stroudsburg, Pennsylvania, I. C. White† found—

Spirifer arenosus (Conrad).
Hipparionyx proximus Vanuxem.
Rensselæria ovoides (Eaton).
Platyceras ventricosum Conrad.

Claypole‡ has given the following species as occurring in cherty beds at Grove tunnel, Northumberland county, Pennsylvania:

Orbiculoidea ampla Hall.
Orthis (*Rhipidomella*) *musculosa* Hall.
Spirifer murchisoni Castelnau.
Spirifer arenosus (Conrad).
Spirifer cumberlandiæ Hall.
Anoplotheca flabellites (Conrad).
Megalanteris ovalis Hall.
Platyceras magnificum Hall.
Platyceras (*Orthonychia*) *tortuosum* (Hall).

Potts Grove, Northumberland county, Pennsylvania:

Spirifer murchisoni Castelnau. 28096.
Diaphorostoma ventricosa (Conrad). 28081.

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* Second Geol. Survey of Pa., vol. G6, p. 123.

† Ibid., p. 124.

‡ Second Geol. Survey of Pa., Sum. Final Rept., vol. ii, p. 1075.

At Three Springs, in Huntingdon county, Pennsylvania, in a coarse, friable sandstone, in the lower 30 feet, were found the following:[*]

Hipparionyx proximus Vanuxem.
Eatonia peculiaris (Conrad).
Spirifer murchisoni Castelnau.
Spirifer arenosus (Conrad).
Rensselæria ovoides (Eaton).
Rensselæria marylandica Hall.
Megalanteris ovalis Hall.
Actinopteria textilis (Hall).
Megambonia lamellosa Hall.
Platyceras ventricosum Conrad.

At Mapleton, Huntingdon county, Pennsylvania, on the Upper Juniata, the Oriskany is about 150 feet thick. *Spirifer arenosus* (Conrad) occurs near the top, and from the lower half was secured—

Eatonia peculiaris (Conrad).
Spirifer murchisoni Castelnau.
Rensselæria ovoides (Eaton).
Platyceras tortuosum Hall.
Platyceras platyostoma Hall.
Diaphorostoma ventricosa (Conrad).

Bedford, Bedford county, Pennsylvania:

Diaphorostoma ventricosa (Conrad). 2063.

Newry, Blair county, Pennsylvania:

Spirifer murchisoni Castelnau. 25362. *Atrypa reticularis* Linné. 25363.

Near Chambersburg, Franklin county, Pennsylvania:

Diaphorostoma ventricosa (Conrad). 3920.

MARYLAND AND WEST VIRGINIA ORISKANY AND ITS FAUNA

In western Maryland, the Oriskany occupies "the central division of the Appalachian region" and enters into the formation of the Alleghany plateau. It follows upon the Helderbergian series, and in turn is overlain by the "Romney formation," the equivalent of the New York Hamilton. In Maryland, the Oriskany is known as the "Monterey formation," and is described by Professor Clark[†] as follows:

> "The Monterey formation, so called for its typical occurrence at Monterey, Virginia, is confined, like the Upper Silurian formation, to the central division of the Appalachian region in western Washington and Alleghany counties, Maryland. The deposits of the Monterey formation are typically rather coarse-grained, somewhat friable sandstones, white or yellow in color. At times the materials become very coarse grained, resulting in a clearly defined conglomerate, while at other times, especially in the western portion of the area, the materials are fine-grained, with here and there interstratified layers of coarse materials. The sandstone is very fossiliferous and carries the typical Oriskany fauna of the north. The formation has a thickness of about 300 feet."

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[*] Ibid., p. 1101.

[†] W. B. Clark: Md. Geol. Survey, vol. i, 1897, pp. 182, 183.

When the writer was at Cumberland recently, Mr Robert H. Gordon pointed out to him the localities which furnished most of the Oriskany fossils. At the "Devils Backbone," the Oriskany follows the Helderbergian, but before the fossils of the former formation appear there is interpolated above what may be the Kingston, beds about 120 feet thick. (See section on page 271.) In the short time devoted to collecting, no fossils were seen, excepting at the base of the formation, where *Anoplotheca flabellites*, a true Oriskany fossil, was found.

Cumberland, Maryland, has long been famous for its splendid Oriskany fossils, which are preserved as silicious pseudomorphs. These were collected by Mr William Andrews, of Cumberland, and were submitted for description to Professor Hall. This enabled him to enlarge considerably the Oriskany fauna described in 1859, in Paleontology of New York, volume iii. Many of the Brachiopoda show not only the interior structure of the valves, but also the processes for the support of the brachia. The Gastropoda are also very well preserved, and are found with other fossils in pockets of loose sand where the shells are free, but usually with the finer surface structure destroyed. Hall writes that "all of the specimens of the Crinoidea of the Oriskany sandstone have been derived from the collection of Mr Andrews," of Cumberland.

The following list contains the names of the species known to occur in the Monterey formation about Cumberland, Maryland:

	Helderbergian.	Lower Oriskany.	Upper Oriskany.
Zaphrentis sp. undet. 28110			
Favosites conicus Hall	x		
" two additional species in the Gordon collection			
Homocrinus proboscidalis Hall			
Technocrinus andrewsi Hall			
" n. sp. (Gordon collection)			
" *sculptus* Hall. Founded on separated calyx plates			
" *spinulosus* Hall			
" *striatus* Hall. Founded on separated calyx plates			
Edriocrinus sacculus Hall. 10661. (In the Gordon collection there are fragments of at least 8 other species of crinoids)			
Anomalocystites disparilis Hall			
Pholidops arenaria Hall (= *P. terminalis*)		x	x
Chonostrophia complanata Hall. 28108			x
Orbiculoidea n. sp. (Gordon collection)			
" *grandis* Hall			x
Orthis (*Rhipidomella*) *cumberlandiæ* Hall			
" " *musculosa* Hall. 8436, 10663			x

	Helderbergian.	Lower Oriskany.	Upper Oriskany.
Orthis (*Dalmanella*) *planiconvexa* Hall	x		
Leptæna rhomboidalis ventricosa Hall	....	....	x
Stropheodonta magnifica Hall. 28111	....	x	x
" *magniventer* Hall	....	....	x
Strophonella headleyana Hall	x	x	
Hipparionyx proximus Vanuxem	....	x	x
Camarotœchia barrandei Hall	....	x	x
" *speciosa* Hall. 10671	..	x	
Rhynchonella ramsayi Hall			
Eatonia peculiaris (Conrad). 8434, 10672	x	x	x
" *sinuata* Hall			
" *whitfieldi* Hall	....	....	x
Spirifer arenosus (Conrad). 10664, 28103	....	x	x
" *murchisoni* Castelnau. 28097	....	x	x
" *cumberlandiæ* Hall (Syn. *S. submucronata* Hall). 10666, 10667			
" *intermedius* Hall			
" *tribulis* Hall. 10668	....	...	x
Metaplasia pyxidata Hall	....	x	x
Cyrtina rostrata Hall	...	x	x
Rhynchospira rectirostris Hall			
Atrypa reticularis Linné. 8432	x	...	x
Anoplotheca dichotoma (Hall)	....	....	x
" *fimbriata* (Hall)			
" *flabellites* (Conrad). 10673	...	x	x
Meristella lata Hall. 28094	....	x	x
" cfr. *princeps* Hall	x		
" n. sp. (Gordon collection)			
Rensselæria cumberlandiæ Hall			
" *intermedia* Hall			
" *marylandica* Hall. 10670, 28088			
" *ovoides* Hall	....	x	x
Megalanteris ovalis Hall	...	x	x
Beachia suessana Hall. 8435, 10669	x		
Centronella ? (probably n. gen. et sp., Gordon collection)			
Platyceras callosum Hall			
" *gebhardi* Conrad. 4201, 28085	x		
" *magnificum* Hall. 28086, 10676			
" *patulum* Hall			
" *reflexum* Hall. 28084			
" *ventricosum* Conrad. 8431, 10674	x		
Diaphorostoma ventricosa (Conrad)	x	x	x
Strophostylus andrewsi Hall			
" *matheri* Hall			
" *transversus* Hall			
Cyrtolites expansus Hall	..	x	x
Tentaculites (near *scalariformis*, Gordon collection)			
Actinopteria textilis arenaria (Hall)	....	....	x
Aviculopecten, 2 or 3 n. sp. (Gordon collection)			
Megambonia lamellosa Hall	...	x	x
Homalonotus vanuxemi Hall	x		
Dalmanites, 2 undet. sp. (Gordon collection)			

On analyzing this Cumberland fauna, it is seen that of the 58 species found there, 25 are restricted and do not occur to the north in New York. Of the remaining 33 species, 10 are also found in the Helderbergian, a far greater number than in the Upper Oriskany of New York, where but 2 species are common to it and the Helderbergian ; 19 are also found elsewhere in the Lower Oriskany and 25 in the Upper Oriskany. The degree of evolution therefore indicates that the Cumberland fauna is older than that of the typical Upper Oriskany of New York, but not quite as old as that of the Lower Oriskany of Becraft mountain.

If this fauna were derived from a limited zone, its developmental progression would indicate that the Cumberland Oriskany is older than the Hipparionyx fauna of New York and not quite as old as that of Becraft mountain. However, it is certain that the Helderbergian here passes without break into the Oriskany, as can be seen at "Devils Backbone," near Cumberland, and it may be that both the Lower and Upper Oriskany are there present. It is probable that Mr Andrews' collection was derived from the entire series, and that there is some mixing. This causes the Cumberland Oriskany to appear older than the Hipparionyx fauna, when it probably contains both the latter and the Becraft fauna.

The following species are from Keyser, Mineral county, West Virginia, and were obtained on the north branch of the Potomac river :

Spirifer arenosus (Conrad). 16674, 16676.
Spirifer murchisoni Castelnau. 16675.
Eatonia peculiaris (Conrad). 16678.
Beachia suessana Hall. 16679.
Stropheodonta magnifica Hall. 16673.
Diaphorostoma ventricosa (Conrad). 16673.

Moorefield, Hardy county, West Virginia :

Spirifer arenosus (Conrad). 28104.

The following forms are from Pendleton county, West Virginia, and were collected on the north fork of south branch of Potomac river :

Orthis (*Rhipidomella*) *musculosa* Hall. 18156, 18157.
Stropheodonta magnifica Hall. 18154.
Stropheodonta lincklæni Hall. 28112.
Hipparionyx proximus Vanuxem. 18155.
Chonostrophia complanata Hall. 18153.
Spirifer arenosus (Conrad). 18158.
Spirifer like *arenosus* in form, but without a plicated fold and sinus. 28106.
Spirifer murchisoni Castelnau. 28100.
Spirifer cumberlandiæ Hall? 28101.
Camarotœchia barrandei Hall. 18159.
Meristella lata Hall. 28092, 28093.
Anoplotheca flabellites (Conrad). 18160.
Rensselæria sp. undet. 18162.
Rensselæria marylandica Hall. 18161.
Diaphorostoma ventricosa (Conrad). 18164.
Platyceras nodosum Conrad. 18165.

VIRGINIA ORISKANY AND ITS FAUNA

In the northwestern part of Virginia, adjoining West Virginia and Maryland, the Oriskany is probably not less than 300 feet thick. It is very difficult to find reliable data concerning this formation to the southwest, and the extract given below is all that the writer has found.

W. B. Rogers,* in his description of the several members of the geological series belonging to the region west of the Blue Ridge, thus describes the Oriskany:

> "(No. 7.)—The sandstones composing this member of the series are, in general, characterized by an open and rather coarse texture, and an extraordinary abundance of organic impressions. In color they vary from a yellowish white to a dark greenish gray. They are usually presented, especially the lighter colored variety, in massive beds of several feet in thickness, and from their frequent occurrence along the flanks and declivities of the ridges, dipping at a steep angle, and bare of vegetation, they form a curious feature in many of the wild scenes among our mountains. . . .
>
> "Nearly all of the mountains of Hampshire, Hardy, Pendleton, Pocahontas, and Alleghany counties, exhibit extensive and instructive exposures of this rock, which from its whiteness, frequently bare surface, profusion of organic impressions, and disposition to disintegrate into a coarse white sand, is one of the most strongly and uniformly characterized of the members of our series.
>
> "An iron ore has been found in various places in connection with these strata" (p. 179).

From Rock Enon Springs, on Great North mountain, in Frederick county, 15 miles northwest of Winchester, in Shenandoah valley, the United States National Museum has received the following fossils collected by Mr Geiger, of the United States Geological Survey:

Spirifer arenosus (Conrad). 15954.
Platyceras magnificum Hall. 15957.
Modiomorpha sp. undet. 15958.

From the northwest pike, six miles from Winchester, *Spirifer murchisoni* and *S. arenosus* (15955) were collected by Mr Geiger.

From the drift about Washington, D. C., and Alexandria, Virginia, have been gathered many characteristic Upper Oriskany species, of which those given below are in the United States National Museum. The origin of this drift is unknown, but it must be either from the west or northwest:

Favosites, ramose form. 18137.
Tentaculites acula Hall. 18166.
Camarotœchia speciosa Hall. 17494.
Anoplotheca flabellites (Conrad).
Spirifer arenosus (Conrad). 28105.
Mytilarca sp. undet. 18149.

In southwestern Virginia, near the Tennessee state line, Professor J. J. Stevenson has observed the Oriskany sandstone in a number of places. It is there never more than 40 feet thick, and may repose either on the New Scotland member of the Helderbergian or on the Clinton. It is always covered by the " Black shale " of Safford or its equivalent in this region—the Hamilton formation of Stevenson. The latter describes the Oriskany as follows:

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* Rept. Geol. Survey Va. for 1837–'38. From "A Reprint of Ann. Rept. on the Geology of the Virginias," Appleton, 1884, pp. 179, 199.

> " This is a sandstone, probably not more than 35 or 40 feet thick, which is shown in the Poor valley of Powell river [Lee and Scott counties, near the Tennessee state line] and along the valleys of Wildcat creek and the North fork of Clinch; also along the latter stream at the foot of Powell mountain, and in the Hunter valley at Stony creek. . . .
>
> " The Oriskany sandstone is coarse, reddish on exposed surface, but white on the fresh surface. It is friable, and at some localities, notably along the North fork of Clinch river, it readily disintegrates on exposure. . . . This rock contains *Hipparionyx proximus* in Stony creek; in the Poor valley of Powell river, it contains *Meristella lata*, but with that there occur some forms [*Spirifer perlamellosus*]* belonging to the Helderbergian.
>
> " The Oriskany was seen only in Bland county, where it is exposed at the foot of Round mountain and the Garden mountains, as well as along the foot of Wolf Creek mountain in the ' Wilderness.' The rock is a thin sandstone, which resists the weather so well as to make a small ridge. . . . As shown in the ' Wilderness,' the rock is a moderately coarse gray sandstone, evidently not more than ten feet thick."†

A Lower Oriskany horizon appears to be present on Flat Top mountain, near Saltville, Smythe county, Virginia. Here in chert were collected the following species, which the writer identified for a correspondent of the United States National Museum:

Leptocœlia, fragment.
Meristella.
Spirifer hemicyclus Meek and Worthen.
Chonetes melonica Billings.
Rhynchospira, near *globosa*, but with three central plications, on each side of which are two large ones.
Zaphrentis, like *Z. rœmeri.*
Platyceras gebhardi Conrad.

CLEAR CREEK LIMESTONE AND UPPER ORISKANY OF ILLINOIS

In the spring of 1858 Professor A. H. Worthen identified the Oriskany formation in Alexander and Union counties, Illinois, but did not describe it until 1866. He then restricted the Oriskany to a " quartzose sandstone " horizon from 40 to 60 feet in thickness overlying his " Clear Creek limestone."‡ The former horizon was then regarded as the base of the American Devonian, but in southern Illinois, he writes—

> " It is underlaid by a group of silicious limestones [Clear Creek limestone], that in their upper beds contain well marked Devonian fossils, and below, those that seem to be characteristic Upper Silurian forms; thus forming beds of passage from the

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* Proc. Amer. Phil. Soc., January, 1881, p. 234.

† Ibid., March, 1887, p. 84.

‡ Geol. Survey of Ill., vol. i, 1866, pp. 124-129.

> Upper Silurian to the Devonian systems. . . . We have, therefore, drawn the dividing line between the Devonian and Upper Silurian, in our general section, through this limestone group underlying the Oriskany sandstone" (pp. 125, 126).

In the second volume, Meek and Worthen * state that "the name 'Clear Creek limestone' was provisionally used for a series of strata holding a position, in Union and some of the adjoining southern counties, between the so-called Hudson River group of the Lower Silurian, and a Devonian sandstone that had been identified with the Oriskany sandstone of New York." Mr Engelmann secured more fossils "at different horizons above the middle of the doubtful series," and these were "found to indicate that at least a considerable portion of these beds are more nearly allied to the Oriskany sandstone than to the Upper Silurian." Meek and Worthen sought to avoid this uncertainty and delayed the printing of volume ii until the region could be revisited by them. This trip resulted in their finding fossils of Helderbergian age in the lower 200 feet of the Clear Creek limestone, a result in harmony with that attained by Doctor Shumard in 1855.† In the upper part of the Clear Creek limestone, or "cherty limestone, or chert formation, as it might properly be called," was found a fauna confirming the conclusion—

> "That a considerable portion of the cherty limestone forming the upper part of the Clear Creek series, as first understood, belongs to the Oriskany period, and that this line between the Upper Silurian and the Devonian, of this region should be drawn between these cherty beds and the strata below, equivalent to those from which we collected the Lower Helderberg. Exactly how far down in the series this line should be carried we are unable to say, as we found no abrupt lithological change, and we saw no fossils near the horizon of the probable junction. From all the facts, however, we are led to believe that possibly as much as 200 feet, and probably more, of these beds should be included in the Oriskany." ‡

The "Clear Creek group" is from this time restricted to the cherty limestones, above a thin band of brown shale of the "Clear Creek limestone," as formerly defined, while the lower half, 200 feet in thickness, is referred to the New Scotland horizon of the Helderbergian. It should also be borne in mind that the passage from the latter into the Clear Creek limestone, as restricted, is not marked, agreeing in this with the passage from the Becraft limestone into the Lower Oriskany at Becraft mountain, near Hudson and Port Jervis, New York.

According to Meek and Worthen,§ the "quartzose sandstone" overlying the Clear Creek limestone contains a small *Zaphrentis*, *Pleurodic-*

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* Geol. Survey of Ill., vol. ii, 1866, p. x.

† Geol. of Mo., 1855, p. 109.

‡ Loc. cit., p. xii.

§ Geol. Survey, of Ill., 1866, pp. xiii, xiv.

tyum problimaticum, *Orthis* (*Rhipidomella*) *musculosa*, *Stropheodonta magnifica*, *Amphigenia elongata* var. *curta*, and *Dalmanites* (*Odontocephalus*) sp. undet. "We have concluded to place it provisionally as an upper stratum of the Oriskany." Since the Clear Creek limestone fauna is to be correlated with that of Becraft mountain, or the Lower Oriskany, it follows that the quartzose sandstone holds the horizon of the typical, or Upper, Oriskany, as developed in Albany and Schoharie counties, New York.

The following Lower Oriskany fauna of the "Clear Creek limestone" of Alexander, Jackson, and Union counties, Illinois, is on the authority of Meek and Worthen:

Anoplia nucleata Hall.
Camarotœchia speciosa Hall.
Eatonia peculiaris (Conrad).
Amphigenia curta Meek and Worthen.
Anoplotheca flabellites (Conrad).
Spirifer engelmanni Meek and Worthen (= *S. worthenanus* Schuchert).
Spirifer hemicyclus Meek and Worthen.
Megalanteris condoni (McChesney).
Strophostylus (?) *cancellatus* Meek and Worthen.
Platyceras gebhardi Conrad.
Platyceras (*Orthonychia*) *tortuosum* Hall.

CAMDEN CHERT OF TENNESSEE

There appears to be no Oriskany present in eastern Tennessee, but in the western part of the state this formation is developed and is apparently a continuation of that of southern Illinois. It is described by Professor Safford* as follows:

> "In March, 1855, the writer discovered in Benton county, Tennessee, at several points, excellent outcrops of Lower Helderberg shales and limestones very rich in fossils. The discovery was important, since it settled the question as to the presence of the Lower Helderberg, as a distinct formation, in Tennessee west of the meridian of Nashville. In subsequent years, this discovery also led to a recognition of the chert now referred to as Oriskany, which I have designated the Camden chert for the reason that at Camden, the county-seat of Benton, is seen one of its best exposures.
>
> "One of the localities discovered in Benton county was a bluff on Big Sandy river, about 5 miles from its mouth, at a point then in Henry county, and known as the old Williams mill site. This locality is referred to in 'Geology of Tennessee,' 1869. As stated on page 325 of that book, there are here exposed about 50 feet of bluish limestone, mostly shaly. Above this and running back on a slope from the precipitous portion of the exposure 'are loose, angular, flinty masses, containing the fossils of the rocks below, and derived from cherty layers not seen.' The fossils in the chert were not numerous nor in good condition, but what was seen of them led, at the time, to the foregoing conclusion.
>
> "In 1884 I recognized the chert at Camden as a distinct formation. I had, in passing through the country, seen this horizon and had referred it without special examination to the 'Silicious group' (lowest of Subcarboniferous), outcrops of

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*Amer. Jour. Sci., June, 1899.

which, very like the chert of Camden, are seen at many points in Benton and counties north and south of it. In my excursion of 1884, however, I stopped for some time at Camden to study the formations. The fossils in the chert arrested my attention, and reminded me of those in the flints seen at Williams' mill in 1855. But at Camden the chert was in comparatively great force, at least 60 feet of it being exposed. At first I was inclined to consider the chert a division of the Lower Helderberg, but subsequent studies of the fossils at home forced me to the conviction that as a group they must be Oriskany. The fact that the formation was one of chert also pointed to this.

"Afterwards, in 1885, 1886, and 1887, I visited localities where I thought the Camden might outcrop. One of these is Big Sandy station, in Benton, on the Memphis branch of the Louisville and Nashville railroad, and near the point where the road crosses Big Sandy river. Here I found the chert well developed and abounding in fossils. The outcrops are as extensive and as good as at Camden. For several miles south of Big Sandy, the chert appears on the hillsides as loose angular gravel.

"Five miles south, on the Lower Camden road, Lower Helderberg limestones are seen cropping out from beneath Camden chert, with Tertiary beds also overlapping all in unconformable contact.

"In Henry county the Camden chert outcrops in considerable areas, west and south of the Williams Mill locality. It is seen in limited thickness above the Lower Helderberg in Decatur county, and in the same relation, east of the Tennessee river, in Stewart county. In the latter locality, it outcrops in the bluff on the Cumberland river below Cumberland city. The greatest development of it, however, is on the west side of the Tennessee river, in a strip of country lying in Henry, Benton, and Decatur counties.

"In 1897 I called the attention of Mr Schuchert to the Camden chert, at the same time trusting he might be able to visit the Camden locality. This he did, collecting a series of fossils, which he studied, kindly giving me the results. I am under special obligation to him for this visit."

CAMDEN LOWER ORISKANY FAUNA

In the spring of 1897 the writer collected Lower Helderberg fossils in western Tennessee, and while in Nashville, Professor Safford also directed his attention to a lot of Camden chert organisms. Since no strata of Oriskany age had been recorded in Tennessee, the importance of determining the equivalency of the Camden chert with other regions made it desirable to know more of its fauna, and with that object in view, a collection was made at Camden.

The fossils of this formation are, as a rule, natural casts both of the interior and exterior of the organism, and preserve in detail the finest markings. This fauna is closely related to that described by Meek and Worthen* from the "Clear Creek limestone" of southern Illinois, in Alexander, Jackson, and Union counties. From this region are known but 11 species, and 8 of these are also found in Tennessee. They are

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*Geol. Survey of Ill., vols. i, ii, and iii.

Anoplia nucleata, *Anoplotheca flabellites*, *Eatonia peculiaris*, *Spirifer worthenanus*, *S. hemicyclus*, *Megalanteris condoni*, *Amphigenia curta*, and *Strophostylus cancellatus*.

The "Clear Creek limestone" of Illinois is intimately connected with the Helderbergian below, and is not less than 200 feet thick, being followed by a "quartzose sandstone" from 40 to 60 feet in depth. The latter is probably equivalent to the Upper, or typical, Oriskany of New York, and does not appear to be present in western Tennessee. From Professor Safford's description of the Camden chert, it is evident that the Lower Oriskany thins rapidly southward. In Tennessee it is about 60 feet in thickness, while it is not less than 200 feet thick in Illinois, exclusive of the Upper Oriskany which is entirely absent in the former state.

The Camden chert fauna contains 32 species, and 6 of these are restricted to southern Illinois and western Tennessee. Of the entire fauna, 24 species are found either in the Helderbergian or in the Lower Oriskany of other regions, and 20 occur in the Upper Oriskany, or Onondaga. After removing the 13 species common to both the Lower and Upper Oriskany and the 2 restricted forms, 17 remain. Of these 10 occur either in Helderbergian or Lower Oriskany rocks of other regions, while 6 are found in higher beds. This evidence therefore indicates clearly a Lower Oriskany age for the Camden chert of Tennessee and the "Clear Creek limestone" of Illinois, which indication is the more marked because of the absence of such characteristic Upper Oriskany species as *Hipparionyx proximus*, *Chonostrophia complanata*, *Spirifer arenosus*, *Rensselæria ovoides*, *Meristella lata*, *Camarotœchia pleiopleura*, *C. barrandei*, or *C. speciosa*.

The following is the Lower Oriskany fauna of the Camden chert of Camden, Benton county, Tennessee:

	In Lower Oriskany elsewhere.	In Upper Oriskany elsewhere.
Zaphrentis roemeri Hall? 26938	H*	
Pholidops terminalis Hall. 26939	x	x
Hipparionyx proximus Vanuxem? A very small specimen of this species. 26940	x	x
Chonetes mucronatus Hall? 26941	......	x
" *melonica* Billings. 26942, 26943	x	x
Chonostrophia reversa (Whitfield). 26944	......	O

* H = Helderbergian ; O = Onondaga.

	In Lower Oriskany elsewhere.	In Upper Oriskany elsewhere.
Stropheodonta (*Leptostrophia*) *perplana* (Conrad). 26945	x	O
Orthothetes woolworthanus Hall. 26947	x	
Anoplia nucleata Hall. 26946	x	x
Cyrtina affinis Billings. 26948	x	x
Metaplasia pyxidata Hall. 26951	x	x
Spirifer hemicyclus Meek and Worthen. 26949	x	
" *tribulis* Hall. 26953	x	x
" *worthenanus* Schuchert. 26950	x	
Anoplotheca flabellites (Conrad). 26954	x	x
Meristella lævis (Vanuxem). 26958	x	
" sp. undet. 26857	......	O
Atrypa reticularis Linné. 26959	x	x
Eatonia peculiaris (Conrad). 26961	x	x
Amphigenia curta Meek and Worthen ? 26962	x	
Rensselæria ovoides (Eaton) ? 26964	x	x
Megalanteris condoni (McChesney). 26963	x	
Tentaculites acula Hall. 26965	x	x
Avicula cfr. *obscura* Hall. 26966	H	
Actinopteria cfr. *textilis* Hall. 26967	x	
Platyceras magnificum Hall ? 26969	......	x
" (*Orthonychia*) *tortuosum* (Hall) ? 26968	x	x
Diaphorostoma turbinata (Hall). 26970	......	O
Strophostylus (?) *cancellatus* Meek and Worthen. 26971	x	
Phacops cristata Hall. 26973	......	x
Ostracoda 26972		
Total, 32 species	24	20

GEORGIA AND ALABAMA ORISKANY

It has been stated that the Oriskany thins out rapidly in Virginia toward the Tennessee state line, and the thickness is given as about 40 feet. Nothing is known of this formation in eastern Tennessee, but it is present in the western part of the state as a chert horizon not less than 60 feet thick. In Floyd county, Georgia, and in Cherokee county, Alabama, the Oriskany is again present, having a thickness of not more than 20 feet. It here bears the name of "Frog Mountain sandstone," and is described by Mr C. W. Hayes * as follows:

> "A few miles southwest of the region mapped [Coosa valley of Georgia and Alabama] the Rockmart slate is overlain by a thin bed of white quartzose sandstone, and this by fossiliferous chert. . . . There are between Indian and Weisner mountains several small areas occupied by a formation which comes in

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* Bull. Geol. Soc. Amer., vol. 5, 1894, p. 470.

contact with all the older rocks thus far described [Middle Cambric to top of Champlainic]. It consists of coarse ferruginous sandstone, in some places white, resembling quartzite, and in others yellow or gray and weathering to incoherent beds of sand. Beneath this sandstone and usually deeply covered by its debris are shales, also variable in composition and appearance. . . .

"A number of fossils have been found [by Mr Cooper Curtice] in these sandstones of Frog mountain [Cherokee county, Alabama]." They include *Zaphrentis* (28109), *Spirifer arenosus, S. murchisoni* (28099), and *Orthis* (*Rhipidomella*) *musculosa ?* "Concerning these fossils Mr Walcott says that all the specific determinations are uncertain, but the horizon of the Oriskany sandstone is strongly suggested by the general facies of the fauna."*

"A few miles south of Cedartown, Georgia, the stratigraphic relations are shown better than in the disturbed region about Frog mountain, though no fossils have been collected. Resting on the Rockmart slate [Champlainic] is a bed of sandstone not more than 20 feet thick, and upon this is a fossiliferous chert."†

On Armuchee creek, at the northeast end of Lavender mountain, in Floyd county, adjoining the Alabama state line, Mr A. H. Brooks, of the United States Geological Survey, gathered unmistakable Oriskany fossils from chert beds, which contain the following species, as identified by the writer:

Orthis (*Rhipidomella*) *musculosa* Hall. 28078.
Stropheodonta magnifica Hall. 28077.
Anoplotheca fimbriata (Hall). 28075.
Spirifer tribulis Hall. 28076.
Meristella cfr. *walcotti* Hall and Clarke. 28074.
Ambocœlia umbonata (Conrad). 28073.

ORISKANY OF CANADA

Cayuga, Ontario.—In the region of Cayuga lake, New York, the Upper Oriskany is sparingly present and is fossiliferous, but west of Ontario county it is only present "in small lenticular patches," or in "nodules of dark colored non-fossiliferous sandstone which hold the position and preserve the characters of the Oriskany sandstone in other localities."‡

The Oriskany sandstone is not again seen until some distance beyond the Niagara river, in the province of Ontario, Canada, near Cayuga. This formation is described by Logan § as follows:

"In the township of Oneida and North Cayuga . . . there are large exposures of the [Oriskany] rock. It is composed of fine grains of white quartz, in some parts so closely cemented as to assume the characters of a white, compact quartzite. . . . The beds are massive, and from 6 inches to 6 feet thick. . . . The greatest thickness of the mass may be about 25 feet, but, though now and then attaining 10 feet, it seldom exceeds about 6, and it is frequently wanting between the Waterlime series and the overlying Corniferous formation."

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* Bull. Geol. Soc. Amer., vol. 5, 1894, p. 470.

† Hayes: Amer. Jour. Sci, vol. 47, 1894, p. 237.

‡ Hall: Pal. N. Y., vol. iii, 1859, pp. 401–.

§ Geol. of Canada, 1863, p. 360.

In 1895 the present writer spent two days in collecting Oriskany fossils for the United States National Museum, at localities about 6 miles northwest of Cayuga. It is from these outcrops that all the Ontario Oriskany fossils are derived which were collected through many years by Mr John De Cew, furnishing Professor Hall his collections. These the writer worked out when assistant to the New York State geologist, and a list of them was published on pages 51–55 of the " Eighth Annual Report of the State Geologist of New York, for the year 1888," issued in 1889. When this work was in hand, it was apparent that there had been some mixing of Corniferous corals with those of the Oriskany fauna, and a number of species were then eliminated. It now appears that more of these corals must be removed from Professor Hall's Oriskany collection, and a number are not included in the list given below.

The unconformity between the Oriskany and the Waterlime groups is not a marked one. A short distance east of Mr David Fleming's farm, the Oriskany is 16 feet thick and rests on the evenly bedded or domed Waterlime group. The contact is well shown, with the bottom of the Oriskany somewhat uneven and filling the fissures in the Waterlime group. On the farms of Mr Fleming and Mr Anderson, the sandstone is not more than 6 feet thick and is abundantly fossiliferous. In other closely adjacent places, the upper layers of the Oriskany are thin bedded, containing rarely a Coral of Corniferous age. Above these layers is the Onondaga chert.

North of the quarry east of Mr Anderson's, the Oriskany is seen in low domes, and in some of the depressions between them thin bedded cherty limestones occur, preserving Bryozoa, trilobites, or an occasional coral of Onondaga age.

Upper Oriskany Fauna of Ontario.—The following forms were obtained in Oneida and North Cayuga townships, Ontario, Canada :

	Also in Helderbergian.	Also in Lower Oriskany.	Also in Onondaga.
Favosites conicus Hall. Hall collection	x	......	x
" *gothlandicus* Lamarck. Geological Survey of Canada	x	......	x
" *hemisphericus* Troost. Geological Survey of Canada	......	......	x
" *turbinatus* Billings. Geological Survey of Canada	......	......	x
" sp. undet. 28054			
" sp. undet. 28055			
Heliophyllum exiguum Billings. Geological Survey of Canada	......	......	x
Cystiphyllum sulcatum Billings. Geological Survey of Canada	......	......	x

	Also in Helderbergian.	Also in Lower Oriskany.	Also in Onondaga.
Zaphrentis prolifica Billings. Geological Survey of Canada			x
Polypora hexagonalis Hall. Hall collection			x
Hemitrypa sp. undet. 28056			
Orbiculoidea ampla Hall			x
Pholidops terminalis Hall. 28057		x	
Chonostrophia complanata Hall			
Chonetes hemisphericus Hall			x
“ *mucronatus* Hall?			x
Orthis (*Rhipidomella*) *livia* (Billings)			x
“ “ *musculosa* Hall 28058			
Leptæna rhomboidalis Wilckens	x	x	x
Stropheodonta demissa (Conrad) var. 28062			x
“ *hemispherica* Hall			x
“ *inæquiradiata* Hall. 28059			x
“ *magnifica* Hall. 14781, 28063		x	
“ *magniventer* Hall. 28061			
“ *perplana* (Conrad). 28060		x	x
“ *vascularia* Hall			
Strophonella ampla Hall			x
Hipparionyx proximus Vanuxem. 14719, 28069		x	x
Orthothetes pandora (Billings)			x
Camarotœchia billingsi Hall			x
Eatonia peculiaris (Conrad)	x	x	
Pentamerella arata (Conrad)			x
Amphigenia elongata (Vanuxem). Geological Survey of Canada			x
Spirifer arenosus (Conrad). 28068		x	x
“ *murchisoni* Castelnau. 28066		x	
“ *tribulis* Hall (= ? *S. duodenarius* Hall). 28067			
Metaplasia pyxidata Hall		x	x
Cyrtina rostrata Hall? (or *C. hamiltonensis?*). 28065		x	
Nucleospira elegans Hall. Hall collection	x		
Anoplotheca dichotoma (Hall)			
“ *flabellites* (Conrad)		x	
Atrypa reticularis Linné. 28064	x		x
Meristella scitula Hall			x
“ *lata* Hall. 28071		x	
“ *lenta* Hall. 28038		x	x
“ *walcotti* Hall and Clarke. 28070			
Rensselæria cayuga Hall and Clarke, 14778, 28039, 28040			
Centronella glansfagea Hall. Hall collection			x
“ *tumida* Billings. Hall collection			x
“ *alveata* Hall. Hall collection			x
Tentaculites arenosus Hall. 28041			
Platyceras carinatum Hall. Hall collection			x
“ *cancavum* Hall. Hall collection			x
“ *dentalium* Hall. Hall collection			x
“ *nodosum* Conrad. 28048		x	
Diaphorostoma ventricosa (Conrad). 28049, 14783	x	x	
Callonema sp. undet. 28050			
Cyrtolites expansus Hall		x	
Loxonema subattenuatum Hall? 28051			x
Actinopteria textilis arenaria (Hall). 28045			

	Also in Helderbergian.	Also in Lower Oriskany.	Also in Onondaga.
Aviculopecten sp undet. 28042			
Pterinea cfr. *flabellum* (Conrad). 28043			
Mytilarca sp. undet. 28046			
Cypricardinia planulata Conrad			
" *indenta* Conrad			x
Conocardium trigonale (Phillips)			x
Conularia near *C. undulata* Conrad			x
Dalmanites (*Chasmops*) *anchiops* (Green)			x
" (*Odontocheile*) *pleuroptyx* (Green). 28052	x		x
Phacops cristata pipa Hall. 28053			x
Proetus crassimarginatus Hall			x
Fish spine			

From the Oriskany sandstone of Ontario, 71 species are now known, and of these not less than 42 are also found in the Onondaga limestone above. The close affinity of this Oriskany fauna with that of the Onondaga is made more apparent when it is noted that 36 species of the 71 constituting the Ontario Oriskany do not occur elsewhere, and that 31 of these are typical Onondaga limestone species. About half the species restricted to the Oriskany of Ontario (36) are therefore early introductions of species characterizing the Onondaga limestone. Further, a person collecting fossils in this region will find difficulty in distinguishing the Oriskany fossils, mainly corals, of the thin upper layers from those of the Onondaga.

That the Ontario Oriskany fauna is probably considerably younger than the Upper Oriskany of New York or of the Appalachian region, is also indicated by the absence of the Esopus grit in Ontario and the many species common to it and the Onondaga cherty limestone. Moreover, of the 71 species found in Ontario, but 16 occur in the Lower Oriskany of New York, and but 8 Helderbergian species are present. These figures, as thus stated, do not so forcibly bring out the fact of its younger age as when it is remembered that 42 of the 71 species are also found in the Onondaga limestone of the same region, while of the 56 species constituting the New York Upper Oriskany fauna, but 11 are in the Onondaga and 30 are present in the Lower Oriskany. In other words, more than half the New York Upper Oriskany species also occur in the Lower Oriskany of the same state, while in Ontario about 60 per cent occur in the Onondaga and but 20 per cent in the Lower Oriskany fauna.

Gaspé, Quebec.—In the counties of Gaspé and Rimouski, unconformably overlying the Quebec group, "is a series of limestones about 2,000 feet in thickness." In regard to these limestones, Billings * writes that—

> "The entire volume of these limestones is about 2,000 feet. The two lower divisions (1 and 2) [160 feet] are most probably Silurian, about the age of the [Lower] Helderberg of the New York geologists. The upper two members (7 and 8) [800 feet] are nearly of the age of the Oriskany sandstone, and are, therefore, about the base of the Devonian. Divisions 4, 5, 6 [880 feet] may be regarded as constituting passage beds between the Upper Silurian and Devonian."

There can be no doubt that "division 8" of the "Gaspé limestone" is equivalent to the Oriskany of New York, and while there are nearly as many Lower as Upper Oriskany species present, the writer inclines to regard this division as of Upper Oriskany age. In the sandstones 1,100 feet above "division 8" occur three Oriskany species—*Stropheodonta blainvillei* (Billings), *Rensselæria ovoides* (Eaton), and *Anoplotheca flabellites* (Conrad). From the same horizon, Billings has described *Zaphrentis corticata*, *Chonetes canadensis*, *C. dawsoni*, *C. antiope*, *Stropheodonta blainvillei*, *S. tullia*, *Spirifer gaspensis*, *Grammysia canadensis*, *Murchisonia egregia*, and *Modiomorphia inornata.* On the basis of the known fossils, there is no positive evidence that the lower 1,100 feet of these sandstones should not be regarded as of Oriskany, or at least of Esopus, age. However, the entire Gaspé limestones and sandstones of more than 9,000 feet thickness appear to represent uninterrupted deposition from early Helderbergian time to the close of the Devonian. Regarding this, Professor Hall † states that—

> "From the Reports of the Canadian Geological Survey we learn that the physical conditions in the northeastern part of that territory, from the beginning of the Oriskany period, continued with little change through a long interval, and so uniform as to have prevented, up to the present time, the establishment of any lines of subdivision among the strata, which in their lower part, bear fossils characteristic of the Oriskany sandstone, and in their higher members those which mark the period of the Hamilton and Chemung groups of New York."

Of the Gaspé limestones and sandstones, Logan ‡ writes as follows:

> "The limestones of cape Gaspé appear, for the most part, to belong to the Lower Helderberg group. The fossils of the summit, however, bear a striking resemblance to those of the Oriskany formation, with which several of them are identical. It appears probable, therefore, that we have here a passage from the Lower Helderberg to the Oriskany, and the latter formation may be more especially represented by the lower part of the Gaspé sandstones. . . . We have already mentioned that a species of *Rensselæria*, identical with or closely resembling *R. ovoides*, which

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* Pal. Fossils, vol. ii, pt. i, 1874, p. 2.

† Pal. N. Y., vol. iii, 1859, p. 404.

‡ Geol. Canada, 1863, p. 403.

occurs in the upper part of the limestones, is met with at 1,100 feet above the base of the sandstone series. This fact, together with the constancy in the lithological characters of the latter, make it not improbable that at least this lower portion of the sandstones, will ultimately be classed with the Oriskany formation" (p. 403).

Ells[*] also regards "divisions 7 and 8" as Oriskany, since he says that—

> "We have therefore drawn the dividing line between the two systems to reach the coast at Cape Gaspé, by which the passage beds [divisions 4, 5, 6 of Logan] will be placed as the upper portion of the Lower Helderberg, while numbers 7 and 8 of the scale (vol. ii, Pal. Foss.), will be assigned to the lower part of Lower Devonian."

New Brunswick, Canada.—In New Brunswick, there is another area of Upper Oriskany on Campbell river, which is described by Bailey[†] as follows:

> "A small area of soft, dark blue, calcareous slates, and soft, dark gray, rusty buff weathering sandstones referable to this age [Oriskany] occurs on Campbell river."

From this locality Doctor H. M. Ami has identified the following forms:

Stropheodonta magnifica Hall.
Stropheodonta varistriata Conrad?
Leptæna rhomboidalis Wilckens.
Hipparionyx proximus Vanuxem.
Orthis cfr. *oblata* Hall.
Anoplotheca flabellites (Conrad).
Eatonia.
Spirifer murchisoni Castelnau.
Spirifer sp. undet.
Actinopteria textilis Hall.
Megambonia?

Oriskany fauna of Gaspé, Canada.—This is "bed 8" of Billings. The specific names in parentheses are Appalachian equivalents. Species with an * also occur in the "Gaspé sandstone" above "division 8."

	Helderbergian.	Lower Oriskany.	Upper Oriskany.	Onondaga.
Zaphrentis incondita Billings				
" *cingulosa* Billings				
Favosites gotlandicus Goldfuss. (Authority of Ells.)	x	....	x	x
Phillipsastrea affinis Billings				
Polypora (?) *psyche* Billings.				

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[*] Geol. and Nat. Hist. Survey of Canada, Rept. Prog., 1882–'84, 1885, p. 25E.

[†] Geol. Survey of Canada, Ann. Rept., n. s., ii, 1887, pp. 8, 9N.

	Helderbergian.	Lower Oriskany.	Upper Oriskany.	Onondaga.
Cystodictya (?) *tarda* (Billings)				
Chonetes melonica Billings		x	x	
“ *mucronatus* Hall		x	x	x
Stropheodonta galatea (Billings)				
“ *blainvillei* (Billings). (Authority of Ells.)				
“ *magniventer* Hall			x	
“ *inæquiradiata* Hall			x	x
“ *irene* Billings (*S. magnifica* Hall)				
Leptæna rhomboidalis (Wilckens)	x	x	x	x
Strophonella punctulifera (Conrad)	x			
Orthis (*Rhipidomella*) *livia* Billings (*O.* (*R.*) *musculosa* Hall)				x
“ (*Dalmanella ?*) *lucia* Billings (*O.* (*D.*) *planiconvexa* Hall)				
“ (?) *aurelia* Billings				
Rhynchonella excellens Billings				
“ *dryope* Billings				
Camarotœchia pleiopleura Conrad		x	x	
Eatonia peculiaris (Conrad)	x	x	x	
**Rensselæria ovoides* (Eaton). 14772		x	x	
**Anoplotheca flabellites* (Conrad)		x	x	x
Atrypa reticularis Linné. (Authority of Ells.)	x	x	x	x
Spirifer superba Billings (*S. arenosus* Conrad)				
“ *arenosus* (Conrad). (Authority of Ells.)		x	x	x
“ *cyclopterus* Hall (probably = *S. arrectus* = *S. murchisoni*)	x	x	x	
“ (*Delthyris*) *raricostus* Conrad				x
Cyrtina affinis Billings		x		
Meristella arcuata Hall. (Authority of Ells.)	x			
Sanguinolites tethys Billings				
Goniophora mediocris Billings				
Mytilarca canadensis Billings (*M.* sp. undet. Cayuga, Ontario)				
“ *nitida* Billings			x	
Actinopteria textilis arenaria Hall. (Authority of Ells.)				
Leptodomus canadensis Billings				
“ *percingulatus* Billings				
“ *mainensis* Billings				
“ *pembrokensis* Billings				
Anodontopsis ventricosa Billings				
Cypricardinia distincta Billings (*C.* sp. undet., Becraft)				
Murchisonia hebe Billings. 14788				
Diaporostoma affinis (Billings) (*D. ventricosa* Conrad)				
Pleurotomaria voltumna Billings				
“ *delia* Billings				
“ *lydia* Billings				
Bellerophon planus Billings				
Proetus phocion Billings				

From the foregoing list it is seen that the Oriskany fauna of "division 8" of the Gaspé limestones has 47 species, of which 27 are not known to occur elsewhere. The 20 species having wide distribution are, with one exception, brachiopods, and 16 of these are Oriskany species, while 2 are Helderbergian and 2 are Onondaga forms. It is the brachiopods that indicate the age of these Gaspé limestones. Of the 19 widely distributed forms, 12 occur in the Lower Oriskany and 14 in the Upper Oriskany. The evidence, therefore, as far as numbers are concerned, is non-committal as to which of the two Oriskany horizons "division 8" should be referred. If the components of this fauna are analyzed, the evidence is somewhat in favor of placing it in the Upper Oriskany. This proof lies either in the degree of development or size of the species when compared with the same forms in Upper Oriskany faunas. The Campbell River locality indicates more definitely the Upper Oriskany horizon.

The reason that so many species are restricted to Gaspé is probably to be found in the difference in the sediments, indicating deeper water. In the Appalachian region the deposits are almost always sandstones—at least those from which the writer has seen fossils—while in Gaspé limestones predominate. Corals and mollusks are rare in the Appalachian faunas, while in the Gaspé fauna they give it a distinct facies.

The great numbers of brachiopods common to Gaspé and the Appalachian Oriskany show that the two areas had free communication, since in their faunal aspect they are almost identical. In fact there is greater diversity in the brachiopods of the Lower Oriskany of Tennessee and New York, than in those of the Upper Oriskany of Gaspé, New York, and Ontario.

Nova Scotia, Canada.—In Nova Scotia, in the region of Nictau, the Oriskany is present and is described by Sir William Dawson* as follows:

> "We reach a band of highly fossiliferous peroxide of iron, with dark colored, coarse slates. . . . The fossils of the ironstone and the accompanying beds, as far as they can be identified, are *Spirifer arenosus*, *Stropheodonta magnifica*, *Atrypa unguiformis* [=*Hipparionyx proximus*], *Strophomena depressa* [=*Leptæna rhomboidalis*], and species of *Avicula*, *Bellerophon*, *Favosites*, *Zaphrentis*, etc. These Professor Hall compares with the fauna of the Oriskany sandstone. . . . The most abundant fossil is *Spirifer nictauvensis* Dawson.
>
> "To the southward of the ore, the country exhibits a succession of ridges of slate holding similar fossils, and probably representing a thick series of Devonian beds, though it is quite possible that some of them may be repeated by faults or folds."

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* Acadian Geology, 3d ed., 1878, p. 499.

In the following year Dawson[*] gave a detailed list of fossils from the Nictau ore and the neighboring beds as follows:

Zaphrentis.
Favosites, like *cervicornis* Edwards and Haime.
Michelinia problematica (Goldfuss).
Stenopora.
Stropheodonta magnifica Hall.
Leptæna rhomboidalis (Wilckens).
Spirifer arenosus Hall.
Spirifer murchisoni Castelnau.
Spirifer nictauvensis Dawson.
Hipparionyx proximus Vanuxem.
Anoplotheca flabellites (Hall).
Rensselæria ovoides (Eaton).
Megambonia lamellosa Hall?
Actinopteria, like *textilis.*
Tentaculites elongatus Hall.
Platyceras.
Bellerophon.
Orthoceras.

Regarding the age of these fossils, he remarks: "The above I hold to be amply sufficient to prove that the beds in which they occur are approximately of the age of the Oriskany sandstone," a conclusion undoubtedly correct.

Doctor H. M. Ami[†] has more recently studied this Nictau Oriskany fauna, and states that—

> "The paleontological evidence at hand from the Nictau district shows the existence there of strata which are for the most part referable to the Devonian system. The following forms are present in several of the collections: *Spirifera arenosa, S. arrecta, Leptocœlia flabellites, Leptostrophia magnifica.* These are of Lower Devonian age and are selected from a considerable number of species as characteristic of that age. . . .
>
> "*Nictau.*—With the exception of the New Canaan limestone fossils, the collections from this region are referable to the Lower or Eo-Devonian epoch. The most complete collection is to be found in the Peter Redpath Museum, and contains 22 species of fossils. The fauna consists, for the most part, of brachiopods, trilobites being very rarely seen. . . .
>
> "*Bear river.*—A very interesting collection made by Doctor Bailey in 1892 has revealed the presence of some 21 distinct species of fossils, whose facies is that of a transitional series. Brachiopoda are predominant, whilst not a single trilobite has been recorded." This fauna is "either at the summit of the Silurian or at the base of the Devonian epoch, the weight of evidence being perhaps in favor of the Eo-Devonian."

Saint Helens Island near Montreal, Canada.—In 1879, J. T. Donald[‡] gave a list of fossils derived from a "dolomitic conglomerate" of Saint Helens island, opposite Montreal. This formation is thus described by Chapman: [§]

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[*] Canadian Nat., vol. ix, 1879, pp. 6, 7.

[†] Geol. Survey of Canada, Ann. Rept., vol. vi, 1895, p. 15 Q.

[‡] Canadian Nat., vol. ix, 1879, pp. 302–304.

[§] Exposition of the Minerals and Geology of Canada, Toronto, 1864, p. 191.

> "At Saint Helens island and Round island, opposite Montreal, on isle Bizard, and one or two neighboring localities, some outlying or small isolated patches of conglomeratic rock, referred to the Lower Helderberg division, have been recognized of late years. Their existence was first pointed out by Doctor Dawson. They are made up of fragments of various rocks, gneiss, Trenton limestone, Utica shale, syenite, etc., cemented together by a paste of grayish dolomite. These conglomerates are regarded as patches of strata once continuous with the Lower Helderberg series of New York."

The Saint Helens Island fauna based on Donald's list contains:

Favosites gotlandicus.
Orthis (*Rhipidomella*) *discus* (Hall).
Orthis (*Rhipidomella*) *oblata* Hall.
Orthis (*Rhipidomella*) *tubulistriata* Hall.
Orthis (*Rhipidomella*) *eminens* Hall.
Hipparionyx proximus Vanuxem.
Orthothetes deformis Hall?
Strophonella punctulifera (Conrad).
Strophonella (?) *radiata* (Vanuxem).
Stropheodonta varistriata (Conrad).
Leptæna rhomboidalis (Wilckens).
Spirifer concinnus Hall. Very abundant.
Spirifer cyclopterus Hall.
Spirifer, allied to *S. arenosus* (Conrad).
Rhynchotrema formosum (Hall).
Lissopleura æquivavis (Hall).
Uncinulus mutabilis Hall.
Uncinulus nucleolatus Hall.
Camarotœchia ventricosa Hall.
Atrypa reticularis Linné. Very abundant.
Stricklandinia gaspiensis Billings.
Anastrophia verneuili (Hall).
Gypidula galeata (Dalman).
Gypidula pseudogaleata (Hall). Very abundant.
Diaphorostoma depressa (Hall).
Tentaculites helena Donald (has vertical striæ between the annulations).

This assemblage of Silurian, Helderbergian, and Oriskany fossils is remarkable, and the present writer hesitated to accept the identifications of Mr Donald without further proof. He therefore wrote to Professor J. F. Whiteaves, paleontologist of the Geological Survey of Canada, who borrowed the specimens of *Hipparionyx proximus* and *Spirifer* allied to *S. arenosus*, of McGill University and sent them to the writer. These show that the Saint Helens Island fauna includes neither *Hipparionyx proximus* nor "*Spirifer* allied to *S. arenosus*." Both these identifications relate to a *Spirifer* apparently near *S. granulosus* Conrad of the Middle Devonian. *S. arenosus* has a plicated fold and sinus, characters not seen in Donald's specimens. His *Spirifer concinnus* Hall is more like *S. cumberlandiæ*, but the bilobed fold of the dorsal shell is a character which associates his species with *S. mucronatus* Conrad, of the Hamilton.

Under these circumstances, judgment is deferred as to the age of the conglomerates on Saint Helens island.

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SILURIAN-DEVONIAN BOUNDARY IN NORTH AMERICA.

BY HENRY S. WILLIAMS

(*Read before the Society December 28, 1899*)

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QUESTIONS INVOLVED IN DETERMINING GEOLOGICAL BOUNDARY PLANES

THE QUESTIONS DEFINED

In the determination of the boundary plane for the rocks of a geological province between two great systems, such as the Silurian and Devonian, there are two distinct questions involved:

1. Conformity to established usage in the application of names and definitions, and

2. Determination of the correlation of local and definite faunas of the region in question with the particular faunas of the standard sections.

The discussion of the first question must conform to rules accepted by those judging the questions. The general principle of historical priority of usage is accepted by all geologists as a fundamental principle in the application of names and their definitions to faunas, formations, and classification.

TOP OF THE STANDARD SILURIAN SYSTEM, THE "TILESTONES" (=DOWNTON SANDSTONE) OF WALES

According to this general principle, the standard definition of the Silurian system is that applied by Murchison to the system so named by him in the classic monograph called "The Silurian System," published in 1839. By this standard the upper limit of the Silurian system is fixed for all future workers. This upper limit was originally placed at the base of the "Tilestones" (Downton sandstone), the highest Silurian formation being the upper Ludlow rock, near Downton castle.* The "Tilestones," lying immediately above it conformably, were then included in the Old Red sandstone.†

In later elaborations of the system the "Tilestones" were transferred to the Silurian because their fossil contents agreed in the main with the fauna of the Ludlow rock below; and Murchison made the explanation that originally it had been associated with the "Old Red" because it was often of reddish color and decomposed to a reddish soil.‡ To this have been added the Ledbury shales of Salter, some 300 feet of red, gray, and purple shales and sandstones, containing Pterygotus and Cephalaspis,§ which by geologists now are recognized as included with the Ludlow rock in the upper part of the Silurian system of Wales.‖ Not only Merostomes (Eurypterus and Pteygotus) and fishes (Onchus, Cyathaspis, and Pteraspis), but also land plants are reported from these upper beds of the Silurian system. The marine invertebrate faunas cease at this point in the Welsh section, and are followed by Old Red sandstone.

BASE OF THE TYPICAL DEVONIAN SYSTEM NOT KNOWN

The Devonian system was established on a different basis. The fossils collected at Plymouth, Torquay, etcetera, in South Devonshire, were

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[*] See Silurian System, p. 197.

[†] Loc. cit., p. 181.

[‡] Siluria, ed. 1854, p. 138.

[§] See Quarterly Journal, vol. xvi, p. 193; vol. xvii, p. 152.

[‖] Kayser: Text-book of Comparative Geology, trans. by Lake, 1893, p. 65.

determined by William Lonsdale to belong to a marine fauna intermediate between those of the Silurian and the Carboniferous rocks, and the rocks containing them were therefore constituted a system by Sedgwick and Murchison in 1838. These fossils mark the rocks which were accepted as the marine equivalents of the Old Red sandstone, to which was applied the name of "Devonian system;"* but in this definition of the Devonian system the lower limit, stratigraphically, was not known in Devonshire. Further elaboration of the lower formations and faunas of the Devonian system has resulted from the study of other faunas in other regions. In the Ardennes and Rhenish regions the lowest Devonian has been called Gedinnian (Dumont, 1848), and in some places rests directly on Cambrian rocks. The Gedinnian is followed above by the Coblenzian (Dumont, 1848). These more western representatives of the European Eodevonian are chiefly shales, sandstones, and grits. On going eastward limestones with marine faunas are met with, and they constitute the Hercynian of the lower Hartz (Kayser, 1870). In Bohemia there is a series of limestones and shales, passing from an unmistakable Devonian horizon (étages G H) downward gradually and conformably into Silurian beds (étage E, Barrande, 1846). In this gradual change in the petrographic make-up of the formations on going eastward, the question to be determined is the place of the division plane between the two systems, in terms of stratigraphy as well as in terms of fossil faunas.

On the principle of priority, one fact can not be ignored. The paleontological boundary can be settled only by first determining how high up in the strata the Silurian fauna is present. In every step it is the base of the Devonian which is uncertain, and every determination of a base of the Devonian is subject to revision until it can be shown that it does not transgress the upper boundary of an established top of the Silurian. The Devonian must adjust to that Silurian limit which is already fixed.

The answer, then, to the first question is clear:

(*a*) The upper limit of the standard Silurian system is already established by definite formations and faunas, and no settlement of any particular case can violate this established precedent. On the other hand, the lower limit of the Devonian in Europe is still under debate, and if lower faunas are discovered which can be shown to be more recent than the Neosilurian faunas, they are to be placed in the Devonian and not added to the Silurian.

(*b*) But this further point is established—*i. e.*, in cases where the correlation with typical standards is doubtful, reason must be shown to prove that the fauna in question is more recent than standard Silurian faunas before it can be put into the Devonian system. So long as the Konieprussian fauna* is recognized to be older than any of the other Devonian European faunas of the same facies, there is insufficient reason for classing it in the Devonian. It must be regarded as Silurian or transitional until it can be proven to be beyond question younger than the youngest of the known standard Silurian faunas. It may be above the Ludlow and still represent the Downton sandstone and Ledbury shales, which are above the Upper Ludlow rock of the typical section, but are still typical Silurian formations.

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* Trans. Geol. Soc. (2), vol. v, 724-727; Quarterly Journal, vol. viii, p. 3.

(*c*) And, thirdly, for determining the equivalency of formations or faunas in other countries, the same final reference to and comparison with the standard Silurian faunas is necessary when doubt is present as to which side of the line the fauna is to go.

(*d*) In the case of the American formations the general question must be determined upon a comparison of the faunas of America with the original standards; of these the upper limit of the Silurian is established by typical sections and faunas; the lower limit of the Devonian seems to be fairly well established in terms of faunas of the facies of sandstone and arenaceous shales, but is in question as to those of a purely calcareous facies. Of the latter, the faunas of Hercyn, Erbray, F_2 Menian, and G and H of Bohemia are accepted as Devonian by paleontologists of Europe, but F_2 Konieprussian can not be taken as of established position above the line so long as its affinities are nearly equally with both the lower and higher faunas, and its exact relation to the typical faunas in Wales is uncertain.

ORISKANY FAUNA OF AMERICA EQUIVALENT TO LOWEST ARENACEOUS DEVONIAN FAUNA OF EUROPE

Taking up the second question, the determination of equivalency, this is no longer a matter to be settled by precedent or priority, but by a close scrutiny of the component species of the individual faunas and their comparison with standards.

In a general way, the facts for America are as follows:

The Oriskany fauna of America has been regarded as the American equivalent of the faunas of the more arenaceous formations at the base of the Devonian system of Europe by De Verneuil, Sharp, Bixby, and James Hall, who examined the fossils when their original classification was prominently before geologists. The only doubt was as to whether the Oriskany might not more properly be classified with the Lower Helderberg in the Silurian. Conrad (and Hall at first) drew the boundary plane still higher in the New York series, but I find no suspicion that the plane was put too high till the Hercynian question arose.

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* The fauna of the Konjepruser-kalk, F_2, Barrande, 1846.

HERCYNIAN FAUNAS EODEVONIAN

In the recent studies of the Hercynian problem it has been established with a fair degree of certainty that the Hercyn and Erbray faunas are Eodevonian, and in a general way an equivalency is established between these faunas and those of the arenaceous beds of the Gedinnian and Coblenzian, not to go into particulars as to the precise place in these étages to which each belongs.

It is also fairly well established that the Oriskany fauna at least represents the same stage of faunal evolution and the same general effects upon a considerable number of different genera, which was expressed in Eodevonian time in western Europe.

IS THE LOWER HELDERBERG EQUIVALENT TO THE HERCYNIAN?

There is difference of opinion, however, regarding the correlation of the Lower Helderberg fauna with European faunas; but there appears to be unanimity of opinion among European paleontologists (Kayser, Frech, Barrois, and others) that while the Lower Helderberg fauna shows affinities with the Hercyn, Erbray, and other faunas of Europe, it is somewhat older; also there seems to be general unanimity of opinion among those discussing the question that the European fauna coming most nearly to equivalency with the Lower Helderberg of America is the F_2 Konieprussian fauna of Bohemia.

THE REAL PROBLEMS IN DETERMINING THE SILURIAN–DEVONIAN BOUNDARY FOR AMERICA

CHARACTER OF THE EVIDENCE AS TO TRANSITION

Accepting these determinations as satisfactorily established, how do the facts affect the question as to the boundary plane between the Silurian and Devonian systems in North America?

It leaves the burden of proof with those who contend that the Lower Helderberg is not in the Silurian; for it is known to be below the base of the Oriskany, and always below, wherever the Oriskany fauna is known in America. Although several species, and closely allied species, appear to associate the two faunas, the case is clear in America that the passage from Lower Helderberg to Oriskany marks a conspicuous evolutional stage in the history of the Paleozoic faunas of North America.

Furthermore, it is clear that this evolutional stage is clearly marked in western Europe by a similar change in the specific characteristics of the species on passing from the top of the Silurian to the first faunas of the Devonian of that region.

In the typical Welsh region the conspicuous geological event marking the passage from Silurian to Devonian is the change from marine to fresh-water conditions and sedimentation, the latter being represented by the Old Red sandstone. This passage was associated with the appearance in the Ludlow of fish and merostomes, and those who have based their opinions on the New York and interior sections of American rocks have assumed that the place of prominent appearance of Eurypterids (viz, the Waterlime), is equivalent to the zone of the "Tilestones" of Europe.

An examination of the Maine, New Brunswick, and Gaspé sections facing toward the Atlantic, and much nearer to Wales, brings out clearly the invalidity of this interpretation. In this eastern region of America the gradual emergence of land, affecting the marine faunas and finally terminating the marine faunas for Paleozoic time, was of a similar nature to that on the opposite shore of the north Atlantic. Furthermore, the exact stage of the physical transition is at a similar point in the evolution of its marine organisms.

MEROSTOMES AND FISHES

The Merostomes, as Walcott has shown, were represented in the Utica (Echinognathus) and possibly in still more ancient pre-Cambrian time. So, too, the fishes are not appearing for the first time in the Ludlow; but, as again Walcott has shown, they were well developed in Trenton time (Astraspis, Eriptychius, etcetera, from Canyon City, Colorado).

Hence the argument based on supposed identity of the Waterlime with the top of the Ludlow because of the appearance in both of merostomes and fishes loses its force. We are obliged from the evidence to believe that throughout Silurian time both fishes and merostomes were in existence. They are liable to occur at any place in the system where the conditions of their living were represented by the formation of strata in which the faunas could be preserved.

SALT BASINS OF WATERLIME AND ONONDAGA OF THE INTERIOR AND THEIR ABSENCE IN MAINE AND NEW BRUNSWICK SECTIONS

In the New York and interior regions there were conditions which shut out, locally, the sea, and in these brackish water pools fish and merostomes appeared; but a comparison of the marine faunas of these regions, below and above the Waterlime, proves that the local elevation, which is expressed in the Onondaga and Waterlime, as well as in the Guelph and Galt, was quite distinct from and at a much earlier geological period than those elevations of far wider extent which introduced the Oriskany faunas. These latter elevations brought about conditions in the extreme east of America quite similar to those of the Old Red sandstone of the opposite side of the Atlantic. The rarity of merostomes and fishes in the Gaspé sandstone does not disprove its general equivalency in time with the Old Red Sandstone period of Wales and Scotland.

If we approach the subject from this wider point of view and follow it down into the particulars of equivalency, the details confirm the grander facts. In the Maine and New Brunswick region, though there is evidence of continuous sedimentation from the base of the Silurian (Anticosti series) through to the Carboniferous, there is no evidence of the local shutting out of the sea, represented by the Guelph, Onondaga, and Waterlime of the interior continental region farther inland.

Nevertheless, the Silurian faunas of these eastern provinces pass through the same faunal evolution observed in the Niagara, Lower Helderberg, and Oriskany stages of the interior, but the separation of the faunas is less marked. In the Anticosti and Gaspé limestone faunas the passage from Niagara to Lower Helderberg is gradual. In several reported cases in this eastern province, species (such as *Halysites catenularia*) which in the interior are characteristic of Niagara and lower range up into association with a fauna which in its general facies is equivalent to the Lower Helderberg, and in the Gaspé limestones the passage upward is still gradual until traces of the Oriskany appear, thus indicating a continuation of similar environmental conditions throughout the whole of Silurian time without the marked change of conditions represented by the Onondaga formation of the interior.

On the other hand, there was a marked change of conditions for the whole eastern province at about the time of the Oriskany fauna. In the Gaspé peninsula this is represented by the change from limestone to sandstone, and an almost total disappearance of marine species, and the frequent presence of land plants.

In eastern Nova Scotia, at Arisaig, the same transition is seen, while in western Maine the marine fauna does not cease till after the Oriskany fauna has appeared. This great change in conditions, contemporaneous with the appearance of the Oriskany, is evident in New York and down the Appalachians as far as Virginia, Tennessee, and even on to Georgia and Alabama.

INTRODUCTION OF ORISKANY FAUNA COINCIDENT WITH ELEVATION OF PRESENT ATLANTIC BORDER OF CONTINENT

Thus the evidence is quite clear to one studying the minute details of the case that it was the introduction of the Oriskany fauna which was biologically coincident with the physical raising of the eastern border of the continent, an elevation which for the Acadian provinces shut out marine conditions permanently, and made dry land after the Coal Measures had been accumulated.

This series of geological events corresponds closely with the events recorded on the British isles, expressed by the estuary conditions of the Old Red, terminating in the Coal Measures, and the final protrusion of land permanently above marine surface. The evolutional changes in the invertebrate organisms, on passing from the Ludlow into the Gedinnian and Coblenzian faunas of western Europe, are also closely paralleled by the evolution taking place in America at this same stage of events on passing from Lower Helderberg to Oriskany.

In America the evidence is clear that the Oriskany fauna was not evolved immediately subsequent to the Waterlime stage, although the Oriskany sandstone immediately follows the Waterlime fauna at Springport, New York. We know that here the Lower and Upper Pentamerus and Delthyris shaly faunas are older than the Oriskany, and also that they are older than the beginning of those physical conditions which mark the great mass of sediments of the Gaspé sandstone.

In Europe it is believed that the Hercyn and Erbray limestones are equivalent to the arenaceous Coblenzian and Gedinnian of western Europe, but it is not perfectly clear what stratigraphical relation exists between the Konieprussian and the arenaceous faunas further west. The doubtful interpretation of the European equivalency should not be allowed to controvert the positive evidence we possess in America as to the place in the time scale at which the transition took place there.

TRANSITION FROM MARINE SILURIAN TO OLD RED SANDSTONE IN WALES SYNCHRONOUS WITH APPEARANCE OF ORISKANY FAUNA IN EASTERN AMERICA

The above evidence points to the conclusion that the appearance of the marine Oriskany fauna among the formations in eastern America marks the exact stage in the geological history which across the Atlantic, in western Europe, is represented by the transition from Silurian to Old Red in Wales, and farther south by the modification of marine faunas from those of the Ludlow into the first arenaceous faunas of the Gedinnian and Coblenzian of western Europe. In regions where these physical conditions did not prevail, a marine fauna of the lower type undoubtedly continued on with less modification, and it is not the continuing of species characteristic of the Silurian into the Devonian which can gainsay the correlation based on positive evolution of new faunas. Where the limestone sedimentation continued unbroken, as in Bohemia, it may be difficult to determine the exact place in the series which represents the transition from the Ludlow to Devonian of the western sections, but in America we are not left in doubt on this point. The Oriskany has a definite and exact place in the historical succession, and it was during the living of the fauna of the Lower Helderberg stage that the events happened which rapidly modified some and destroyed other species and left a clearly new fauna, first seen in the Oriskany, to dominate the whole eastern border oceans of the American continent.

Summary of Geological and Stratigraphical Argument

The geological and stratigraphical argument may be summed up in the following words: A comparison of the geological history of the two continents facing each other, at the point where they most nearly approach each other, shows a general uniformity in the order and sequence of sediments throughout the Silurian. This fact is particularly marked in those points by which the eastern sections differ from those of the interior of North America (that is, absence of either an Onondaga basin or a sharp separation of the Niagara and Lower Helderberg faunas).

This comparison also shows that the geological changes which are expressed in a sharp transition from marine to brackish water deposits terminate the Silurian sections for both continents, and that the place of this transition is definitely located in America where the Oriskany fauna follows that of the Lower Helderberg. The inference is that the place of this transition in America represents, in time, the corresponding place of transition in the standard sections in Wales. In Wales this is the boundary plane between the Silurian and the Old Red Sandstone phase of the Devonian system.

The Paleontological Argument

NATURE OF THE EVIDENCE

It remains to show that paleontological evidence confirms this conclusion. Two cases are in evidence, namely, the recognition of the Tilestone fauna at the top of the Silurian section at Arisaig, Nova Scotia, and the recent discovery of the same fauna in the Chapman sandstone of northern Maine.

In both cases the faunas are the most recent Paleozoic marine faunas of their respective sections, and they appear at the point of transition from the typical Silurian into the Old Red Sandstone phase of the Devonian.

The "Tilestones" have already been referred to as constituting the topmost formations of the typical Silurian system. Their fauna is quite distinct, in the majority of its species, from the Ludlow fauna of the underlying calcareous shales and limestones, but it is made up chiefly of marine species, with some traces of land plants and of merostomes and fishes, of types similar to those which follow. Nevertheless, a few characteristic Ludlow species tie the Tilestone fauna with the typical marine Silurian. The formation was more definitely described by geologists following Murchison, and now goes under the names Downtonian, Downton sandstone, and Ledbury shales. The fauna is evidently a transition fauna, and, as far as reported, appears only in sections in which the following formations lack purely marine fossils.

THE TILESTONE FAUNA RECOGNIZED IN THE UPPER ARISAIG BY J. W. SALTER

This Tilestone fauna was first discovered on the American continent by Doctor D. Honeyman, in the Upper Arisaig rocks of northern Nova Scotia. The identification of the fauna with the Tilestone fauna of Wales was made by J. W. Salter, then paleontologist of the Geological Survey of Great Britain; an account of it was first published in 1864.

The Arisaig rocks were brought to notice by Doctor J. W. Dawson* (the late Sir William Dawson) in 1849, who then interpreted them to be of Silurian age. In "Acadian Geology" they were referred to the Devonian.† Honeyman,‡ having studied the fossils and compared them with Murchison's Siluria, considered them mostly equivalent to the Upper Ludlow in 1859. In the following year Dawson,§ after more careful study and the identification of fossils by James Hall, published a further description of the rocks, in which he referred the series to the "upper part of the Middle Silurian, probably with a part of the Upper Silurian." In the same volume the species of the fauna are described by James Hall.||

In his descriptions of the species of this fauna James Hall considered most of them new, and because of resemblance in a few cases to Clinton species, they were supposed by him to represent a Clinton horizon, and I observe that the species are now commonly listed as Clinton species. It appears to be this interpretation to which Salter refers in the passage quoted below. It appears further, from notes published later by Honeyman, that this peculiar fauna occurred in the uppermost part of the zone D of his 1864 paper, which was called E in that article.¶ This shows that the fauna follows, in the Arisaig section, the representative

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* Quarterly Journal Geol. Soc., vol. vi, p. 347.

† See Acadian Geology, 1855 edition.

‡ On the fossiliferous rocks of Arisaig. Trans. Lit. and Sci. Soc. Nova Scotia, 1859.

§ On the Silurian and Devonian Rocks of Nova Scotia. Can. Nat. and Geol., vol. v, 1860, p. 132.

|| James Hall: Description of new species of fossils from the Silurian rocks of Nova Scotia. Can. Nat. and Geol., vol. v, 1860, p. 144.

¶ Trans. Nova Scotia Inst., vol. iv, p. 55.

of the Lower Helderberg. Preparatory to the international exhibition of 1862, Doctor Honeyman* made a collection of the Arisaig fossils for Sir R. Murchison, which were submitted to J. W. Salter for identification. By this means the equivalency of the Upper Arisaig fauna was established.

Regarding this identification Honeyman writes in the paper above cited:

> "Sir Roderick Murchison, at my request, very kindly asked Mr Salter to examine it [collection of Arisaig fossils and rocks], who accordingly inspected my divisions of fossils, and, studiously avoiding all inquiry into the opinions already entertained, he unhesitatingly referred my Upper Ludlow to the Ludlow Tilestone my Wenlock (?) to the Aymestry limestone, and Hall & Dawson's Clinton to a repetition of the Ludlow Tilestone." †

In this paper Honeyman published a list of the species of the Upper Arisaig from the rocks west of Arisaig pier, near McAra's brook, containing fifty-eight entries. In this list are found four species identical with the Tilestone fauna of Murchison's Silurian system; two others are apparently identical, but differently named, and most of the species of the two faunas are very closely related representative species.

In 1887 a report on Nova Scotian geology was published in the Annual Report of the Canadian Geological Survey by Fletcher and Faribault.‡

The section of the upper 1,038 feet of the Arisaig rocks is given in this report of 1887 as follows. It is compiled from the exposures along the gulf shore between McAra's brook and Arisaig pier. It is E 6 of their classification, and is called Lower Helderberg. It rests on E 5, the Niagara. The junction of the two at Joseph McDonald's cove is shown by a photograph taken by T. C. Weston (number 6, opposite page 40P):

Section of Silurian Rocks at Arisaig in descending Order

E 6. LOWER HELDERBERG:

	Feet
1. Reddish and purplish altered flags with bright emerald green blotches and layers; more or less argillaceous, flinty, and splintery, containing thin calcareous layers full of blackened shells. The red and purple beds greatly predominate. They end about 15 yards northeast of McPhersons brook. Dip, 166°<46°	100
2. Dirty green, greenish, and gray quartz-veined flags and shales, holding encrinities and shells in abundance; seen in Stonehouse brook as well as on the shore. Veins cut across the bedding and are sometimes three inches thick; perhaps unconformable to 1. Dip, 207°<41°; end at the mouth of Joseph McDonalds brook	310

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* On the Geology of Arisaig, Nova Scotia, by D. Honeyman, Quarterly Journal Geol. Soc., vol. xx, 1864, p. 333, etc.

† Quarterly Journal Geol. Soc., vol. xx, p. 334.

‡ Rept. Geol. Survey and Expl. in counties of Guysborough, Antigonish, Pictou, Colchester, and Halifax, Nova Scotia, from 1882 to 1886, by Hugh Fletcher and E. R. Faribault, pp. 1P to 163P.

	Feet
3. Dirty greenish rocks, finely ripple-marked, full of fossils. Dip, 203°<32°	205
4. Dirty green and gray, rubbly or prismatic, rusty weathering argillo-arenaceous flags; the bottom of Doctor Honeyman's group D—Lower Helderberg or Ludlow Tilestone (Quarterly Journal of the Geological Society of London, 1864). Dip, 194°<38°	393
5. Indian red crumbly prismatic marl, with a thin band of gray limestone full of fossils; in the upper part mixed with bright green patches and full of calcareous nodules, like the rock of Indian brook, cape George. The green of the beds immediately overlying is brighter than usual, and the whole mass is more or less concretionary and nodular. This is Doctor Honeyman's "red stratum" (op. cit., p. 336), and is also described in Mr Weston's section and shown in view number 6. Dip, 169°<34°. It has been traced more than half a mile eastward of the Trunk road	30

The classification of the rocks of the whole Arisaig section is as follows:

E^6	Lower Helderberg	= division	D	of Doctor Honeyman	= Upper Ludlow Tilestone.
E^3	Niagara	=	C	"	= Aymestry limestone.
E^2	Upper Clinton	=	B^1	"	= Lower Ludlow.
	Lower Clinton	=	B	"	
E^1	Medina	=	A	"	= Mayhill sandstone. (p. 37P).

The part of the section given above constitutes division E^6, Lower Helderberg, of this classification.

FIFTEEN LOWER HELDERBERG SPECIES RECOGNIZED IN ARISAIG SECTION BY DOCTOR AMI

The species collected by Mr Weston from this Arisaig section in 1886 were identified by Doctor H. M. Ami, and a report of them is published in the Proceedings of the Nova Scotian Institute in 1892.* In this list 15 species are Lower Helderberg species. The species of the western collection described by Billings† were all collected, according to the Fletcher and Faribault report (p. 48P), by Mr Weston from the upper part of this formation [E^6, Lower Helderberg], west of Stonehouse brook, where fish remains were also obtained by him. They are identified as of Upper Silurian age by Billings, and all the species are described as new except one—*Sanguinolites anguiliferus?* McCoy.

The rocks for this portion of Nova Scotia succeeding the Silurian of the Arisaig section were classified by Fletcher and Faribault as Devonian.* Their identification with previously described formations of the eastern provinces is as follows:

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* Silurian fossils from Arisaig, Nova Scotia, by H. M. Ami (read April 11, 1892), Proc. and Trans. Nova Scotian Inst. of Sci., Halifax, 2d ser., vol. i, pt. i, pp. 185–192.

† Paleozoic Fossils, vol. ii, part i. 5. On some of the fossils of the Arisaig series of rocks, Upper Silurian, Nova Scotia, pp. 129, etc.

F^3, Upper Red slate and sandstone = Mispec group.
F^2, Middle gray sandstone and slate group = Dadoxylon sandstone and cordaite shale.
F^1, Lower conglomerate group = Bloomsbury conglomerate.
E^6, Lower Helderberg

PLACE OF TILESTONE FAUNA IN ARISAIG SECTION EQUIVALENT TO TRANSITION FROM MARINE TO ESTUARY CONDITIONS IN GASPE SECTION, AND TO FIRST APPEARANCE OF ORISKANY IN MAINE AND NEW BRUNSWICK

The paleontological evidence of this Arisaig section appears therefore to be as clear as the general geological evidence in fixing the place of the Silurian-Devonian boundary for the American continent. This evidence may be summed up as follows:

In the Arisaig section, at the point where the marine conditions pass up into non-marine, a transition fauna appeared (D of Honeyman's paper), which was unhesitatingly identified as the equivalent of the topmost fauna of the typical Silurian system of Great Britain by the official paleontologist of that survey, during the lifetime of Murchison, the founder of the Silurian system.

This fauna appeared after the Lower Helderberg fauna was in the region, as shown by the recognition of at least fifteen Lower Helderberg species in the Upper Arisaig formation by Doctor Ami.

No marine paleozoic fauna later than the Nictaux, containing some Oriskany species, is recorded for this Nova Scotia region.

In New Brunswick, in the Gaspé peninsula, the same general sequence is repeated. The Gaspé limestone carries a fauna which has been defined as equivalent to the Niagara and (its upper part) Lower Helderberg. No Tilestone fauna has been identified in these rocks, but the place of transition from the limestones into the following Gaspé sandstones was recognized long ago by Logan as nearly equivalent to the Oriskany of the New York section. The following sandstones contain almost no marine fossils, but hold plants (Psilophyton, etcetera) of Devonian age. The place of termination of the marine faunas is equivalent to the place of the transition in the Arisaig section from upper Arisaig to Devonian; and both correspond as closely as could be wished with the transition from Silurian into Old Red sandstone in southern Wales.

In Maine I have recently recognized another representative of the Tilestone fauna, in a formation to which I gave† the name of Chapman sandstone, in the report on the geology of Maine above referred to. The identification of this fauna with the Tilestone fauna of Murchison was made before I observed the fact that Salter had positively identified Honeyman's Arisaig fauna D as equivalent to the Tilestone. In presenting the facts before the Society, I have therefore given precedence to the Arisaig facts, and I omit the paleontological argument by which the correlation of the Chapman and Tilestone fauna is established, which will be published hereafter.* The species of the Chapman sandstone and the upper Arisaig are, in several cases, identical, so far as I can judge from reading the descriptions, and the whole contents of the two faunas are very much alike. The Chapman sandstone fauna is the latest of the marine Paleozoic faunas of Maine, and, what is still more significant, a Psiloplyton stem is found associated with the marine fossils in the Chapman sandstone. In the Chapman sandstone there are a few species with which to correlate the fauna with another, found in western Maine, about Moose river, in which a distinctly Oriskany fauna is recognized. This shows that the Chapman fauna is closely related to the Lower Oriskany of New York. In Maine (Aroostook county), the Square Lake limestone, which is correlated with the upper part of the Gaspé limestone, contains a distinctly Lower Helderberg fauna, thus establishing for the Lower Helderberg a place in the scale earlier than the representative of the Welsh Tilestone (my Chapman sandstone), and hence unquestionably in the typical Silurian system.

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* Loc. cit., p. 49P.

† Bulletin No. 165, U. S. Geol. Survey.

Summary and Conclusions

Thus, the Arisaig, the Gaspé, and the Maine sections are in harmony in fixing the exact boundary between the Silurian and Old Red sandstone (Devonian) on the American continent. As near as I am at present able to identify this boundary in the New York sections, it comes very close to the transition from the Lower Oriskany of Becraft mountain into the Upper, or pure Oriskany of Oriskany falls. This point will be developed as the faunas are more fully studied. The facts already noted, however, are clear in establishing the fact that the Lower Helderberg fauna lies below the Chapman sandstone, and the equivalent upper Arisaig, faunas, both of which are the paleontological representatives on this continent of Murchison's Tilestone fauna (Downton sandstone and Ledbury shales), the highest known fauna of the typical Silurian system.

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*See Am. Jour. Sci., vol. ix, p. 203.

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SILURO-DEVONIC CONTACT IN ERIE COUNTY, NEW YORK

BY AMADEUS W. GRABAU*

(Read before the Society December 28, 1899)

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*I take pleasure in acknowledging the kindness of Professor John M. Clarke, who gave me permission to study collections of Manlius and Coralline limestone fossils in the New York State museum. Professor Clarke has independently discovered the unconformity in the contact in Erie county, and has discussed its significance in a forthcoming memoir. He has also in repeated discussions given me the full benefit of his critical knowledge of the horizons here described. It should be stated that the general conclusions herein set forth have been arrived at independently by both Professor Clarke and myself. The fossils described have been deposited in the State collection at Albany.

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INTRODUCTION

Throughout the greater part of western New York the contact of Siluric with Devonic strata is traceable in the northward facing escarpment of the Onondaga limestone terrace. This terrace is a good example of a cuesta developed on an ancient coastal plain, the drainage adjustment of which has been greatly modified by glacial deposits. The northward facing scarp or "inface" of this cuesta is a prominent topographical feature of western New York, paralleling that of the Niagara cuesta which lies from 15 to 20 miles farther to the north.

The inface of the Onondaga cuesta first appears in Erie county, in the northern part of the city of Buffalo and a mile or two east of the Niagara river. Between this point and the river, extensive drift deposits have obscured the cliff, which, however, has been definitely located by excavations and borings.* From the point of its first appearance on Scajaquada creek eastward, it increases in prominence and elevation, until at the county line it is about 80 feet in height, increasing to about a hundred feet in Genesee county. Between Buffalo and Williamsville the cliff is divided into two parts, with a flat terrace of varying width up to 200 yards separating them. This division is along the line of contact between the Siluric and the Devonic. At Williamsville, Ellicott creek descends in a series of falls over the cliff, producing very good natural exposures of the strata. At Harris hill and Clarence hollow other small streams descend northward over the cliff. At Falkirk, Murder creek has cut a gorge of some magnitude into the northern face of the cuesta, over which it descends, likewise in a series of small falls and rapids. All these streams are tributary to the Tonawanda, which has another branch, bearing its own name, descending over the cliff at Indian falls, several miles east of the county line.

The summit of the cuesta is formed by the resistant Corniferous beds of the Onondaga limestone series, while the more fossiliferous, chert-free lower beds of this series and the Manlius limestone and the Waterlime lie at the base. The latter rock is rarely exposed in its totality in Erie county.

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* Bishop, 1895, p. 312.

The only good natural exposures of the beds comprised within the cuesta are in Skajaquada, Ellicott, and Murder creeks, in Erie county, and at the falls of the Tonawanda or Indian falls, in Genesee county. The contact between the Siluric and Devonic beds is shown in all these exposures. The numerous quarries which are opened in the northern face of the cuesta furnish, however, the best means for the study of the contact and the beds adjoining it. Where the quarries are opened for lime only they seldom penetrate below the Onondaga limestone, but where building stone is quarried or where the Waterlime is the object of search, good sections are usually produced. By far the best of these are in the quarries of the Buffalo Cement Company, in North Buffalo. The old park quarry, the abandoned cement tunnels at Williamsville, and the cement mines at Falkirk and Akron furnish other satisfactory exposures.

Upper Silurian Rocks of Erie County

SALINA BEDS

The Upper Silurian rocks of New York have been divided by Clarke and Schuchert (1899) into the Salina beds, at the base, the Rondout Waterlime, in the middle, and the Manlius limestone, on top. The Salina beds are scarcely exposed in Erie county, the only localities mentioned by Bishop (1895) being on Grand island and in the bed of Murder creek below the falls at Falkirk.

RONDOUT WATERLIME

This name has been resuscitated by Clarke and Schuchert for the hydraulic limestone or Waterlime of New York—that is, the formation characterized by the Eurypterus fauna. This is a very important formation in Erie county, being extensively quarried for hydraulic cement. The most satisfactory exposures for purposes of study are in the cement quarries in North Buffalo. Here the stratum quarried for burning is 5 feet 8 inches thick (Bishop), and is exposed by the stripping off of the overlying strata. The rock is compact, very fine and evenly grained, and breaks with a conchoidal fracture. The fauna obtained from this stratum comprises, according to Mixer,* 9 species of Eurypterus, 7 of Pterygotus, 2 of Ceratiocaris, a Leperditia, 5 species of Discina (Orbiculoidea ?), a Lingula, and 2 (?) seaweeds.

At Akron the cement stratum is 7 feet thick, and at Falkirk, near by, it ranges from 7½ to 8 feet. The total thickness of the Rondout Waterlime in Erie county is, according to the measurements given by Bishop, something over 50 feet, including the cement stratum.

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* Bishop, 1895, p. 340.

MANLIUS LIMESTONE

Occurrence and general character.—This rock, the Tentaculite limestone of most authors, is represented in Erie county by a stratum of limestone locally known as the " Bull Head " rock. This stratum has a thickness of 7 feet in North Buffalo and 8 feet at Williamsville and Akron. It rests immediately on the Rondout Waterlime, the passage from the one to the other being a gradual one. The rock is a dolomitic limestone of a very compact, semi-crystalline character, with a high per cent of argillaceous material and not infrequently a strong petroleum odor. It is mottled, having frequently the appearance of a limestone breccia, and consists of purplish gray angular or rectangular pieces and similar light colored and more yellowish ones. These latter appear to be more argillaceous than the former. Sometimes fragments of the purple rock seem to be included in the yellow, while again in other cases the yellowish rock is inclosed by the purplish. Careful examination of thin sections has not revealed any striking differences in character between the two kinds of rock, except that the lighter colored portion is perhaps more coarsely crystalline. The brecciation, if brecciation it is, is only marked distinctly by the contrast in color between the two fragments, the rock having otherwise a nearly uniform texture. The yellowish fragments weather much more readily when exposed than do the purplish, the lime being dissolved and an earthy residue remaining.

This rock is commonly very porous in its upper portion, the cavities being often lined with crystals of calcite or other minerals. The smaller of the cavities are due to the dissolving out of the small coral *Cyathophyllum hydraulicum*, which was exceedingly abundant in the upper portion of the stratum. This coral has long been known, but has only recently been described. Hall,* in 1843, stated that on Skajaquada creek the upper portions of the Waterlime "abound with cavities, many of them containing sulphate of strontian, but principally empty, and showing the remains of a small coral, which has been partially removed."

At Williamsville the rock is of a similar character ; " about 3 feet of the upper part are unfit for burning, being too calcareous. Below this there are 4 feet of good quality, and then a shaly mass of 2 or 3 feet thickness, below which the rock is fit for cement."† About 8 feet of this mass is referable to the Manlius limestone.

At Akron the upper fossiliferous portion is more friable and earthy, and has frequently a strong petroleum odor.

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* Hall, 1843, p. 471.

† Hall, 1843, p. 470.

In many places in the cement quarries of North Buffalo the upper part of the Manlius limestone is rich in pyrite, which commonly occurs in small cubes, not infrequently oxidized to limonite. Green stains of malachite, probably from decomposed chalcopyrite, are not uncommon, the latter mineral being disseminated in minute grains. Many of the geode cavities contain scalenahedra or acute rhombohedra of calcite, as well as sulphate of strontian. An analysis of the Manlius limestone of the Buffalo cement quarry, made by Messrs P. N. Coupland and E. Fales, students in the Rensselaer Polytechnic Institute, gave $CaCO_3$ 47.23 per cent and $MgCO_3$ 19.25 per cent. A sample of the cement bed of the Waterlime from Akron, New York, gave Messrs Gilmore and Reid $CaCO_3$ 35.60 per cent and $MgCO_3$ 19.26 per cent.*

Faunal relations.—While the Bullhead limestone undoubtedly occupies the position of the Manlius limestone of eastern New York, being its stratigraphic equivalent, it is quite distinct from it in lithologic character as well as faunal contents. That the two types of deposits grade into each other somewhere east of the Erie county line is, I believe, an established fact. If, however, we compare the Manlius of Erie county with that of the Helderberg mountains—that is, the well known Tentaculite limestone—we are forced to conclude that two distinct facies of this limestone are represented within the state—an eastern calcareous and a western dolomitic—each with its distinct faunal types, both, however, showing unmistakable relationship.

The following species have so far been found in this rock in Erie county (see page 363 for descriptions):

PLANTÆ:
- *Nematophyten crassum* Penhallow, rare.

ACTINOZOA:
- *Cyathophyllum hydraulicum* Simpson, common.

BRACHIOPODA:
- *Orthothetes hydraulicus* (Whitfield), common.
- *Spirifer eriensis* sp nov.
- *Whitfieldella sulcata* (Vanuxem).
- *Whitfieldella* cf. *rotundata* (Whitfield), rare.
- *Whitfieldella* cf. *lævis* (Whitfield).
- A rhynchonelloid.

GASTROPODA:
- *Loxonema?* sp. rare.
- *Pleurotomaria?* sp. rare.

CEPHALOPODA:
- *Trochoceras gebhardii* Hall, rare.

CRUSTACEA:
- *Leperditia scalaris* Jones, common.

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*Chamberlin, 1877, p. 395,

A careful analysis of this rather meager fauna reveals the interesting fact that in its individual species and in its *ensemble* it bears a striking similarity to the fauna of the Coralline limestone of Schoharie county. *Trochoceras gebhardii*, originally described from the Coralline limestone, is not otherwise known outside of it. This species has been found at Williamsville by the New York State Survey, and recently a very fine specimen has been found in the cement quarries at Buffalo by Messrs Vogt and Piper, of the Buffalo high school.

Leperditia scalaris, the only crustacean so far obtained from the Manlius limestone of Erie county, is the representative of *L. jonesi* of the Coralline limestone. Both are typical Silurian Leperditiæ and related to species occurring in the Niagara limestone. Among the brachiopods of the Bullhead, *Orthothetes hydraulicus* and *Spirifer eriensis* have their respective representatives in the Coralline limestone in *Orthothetes interstriatus* and *Spirifer crispus* var. *corallinensis*, nom. prop. This latter variety differs from the normal *S. crispus* of the Niagara in its uniformly obsolescent plications and angular mesial sinus, characters which most strongly ally it to *S. eriensis*. The typical Manlius limestone Spirifer, *S. vanuxemi*, is much more closely related to the typical *S. crispus* than to *S. eriensis*, which is its western representative, while, again, *S. crispus* var. *corallinensis* has more points of resemblance to *S. eriensis* than to the typical Niagaran *S. crispus*. *Orthothetes hydraulicus* and *Orthis* (*Orthothetes*) *interstriatus* are, as far as I have been able to compare them, indistinguishable.

Whitfieldella sulcata is a typical Manlius limestone species occurring in that rock in central and eastern New York. It is not represented in the Coralline limestone. *W. rotundata* (?) is represented by *W. nucleolata*, but *W. lævis* (?) has no representative in the Coralline limestone.

Westward extension of the Manlius limestone.—In Ohio the Manlius and the Rondout limestones have not been differentiated. The two together are known as the Waterlime, though not suitable for purposes of hydraulic cement. The rock is in the main a compact magnesian limestone, chiefly drab or brown in color, but occasionally becoming very light colored, and again of a dark bluish color.* In the northwestern part of the State the thickness is given by Orton as at least 600 feet, while in southern Ohio the thickness is only 100 feet. "Throughout much of its extent it is brecciated, the bed seeming to have been broken into sometimes small and sometimes large angular fragments after their hardening, and then to have been recemented without further disturbance." †

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* Orton, 1893, p. 15.

† Orton, loc. cit.

In addition to this brecciation the series contains "an immense amount of true conglomerate," in which the pebbles, derived from the limestone, often are of enormous size, even up to a ton in weight. This intraformational conglomerate is best developed in Lucas county, near the extreme western end of lake Erie, and furnishes ample proof of shallow water, if not repeated land conditions, during the formation of these deposits. Sun cracks and thin layers of carbonaceous matter are further proofs of shallow-water conditions. The petroliferous character of the Manlius limestone noted at Akron and other places in Erie county is also a very characteristic feature of this rock in Ohio, where, moreover, streaks and masses of asphaltum occur.

In the northwestern portion of Ohio and the adjacent territory in Michigan, the Waterlime has interpolated between its members, beds of pure quartz sand, of which that known as the Sylvania sandstone, used for glass making, has a thickness of 20 or more feet in the Sylvania quarries, and lies at least 200 feet below the Corniferous limestone.* The following species have been described by Whitfield (1893) from this rock at Greenfield, in Highland county, Southern Ohio:

Streptorhynchus (*Orthothetes*) *hydraulicum* Whitfield (also at Belleville, Sandusky county).
Meristella lævis (Vanuxem).
Meristella bella (Hall).
Nucleospira rotundata (Whitfield).
Retzia (*Rhynchospira*) *formosa* Hall.
Rhynchonella hydraulica Whitfield.
Leperditia angulifera Whitfield.

From Put-in-Bay island, where this rock is well developed, the following species have been described :†

Spirifer vanuxemi Hall.
Pterinea aviculoidea Hall.
Goniophora dubia Hall (also from Marion county).
Eurypterus eriensis Whitfield.

Leperditia alta Conrad was described from Bellevue, Sandusky county, and *Pentamerus pes-ovis* Whitfield from Adams county.

In the Lower Peninsula of Michigan the Oriskany is represented, according to Rominger (1876), by a soft, friable, occasionally perfectly white, sandstone. It contains impressions of Spirifer, of bivalves, and of gastropods. In places it is almost pure quartz, without admixture of foreign substances, and is extensively used for making glass. Its thickness is 6 or 7 feet in most places, and it never exceeds 8 or 10 feet.

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* Orton, 1893, p. 17.

† Whitfield, loc. cit.

The sandstone rests on a "hard, compact dolomite rock, mottled with light and dark blue cloudy specks, resembling castile soap." These strata, referred to the Lower Helderberg by Rominger, are frequently, though not always, brecciated, with fragments of various ledges intermingled and recemented. The brecciated condition is traceable throughout a great portion of the Peninsula, is very prominent on the island of Mackinac, where the concretionary and conglomeritic phases also occur, and is noted again at Goderich, in Canada.

Often "a regular unbroken seam of limestone alternates with the brecciated layers."* The lower non-brecciated beds are of the same lithologic character as the fragments composing the breccia.

The fossils obtained from these beds include, according to Rominger:

Meristella lævis (Vanuxem).
Leptocœlia (*Cœlospira*) *concava* Hall.
Retzia (*Rhynchospira*) *globosa* Hall.
Megambonia (*Pterinea*) *aviculoidea* Hall.
Spirorbis.
Cyrtoceras.
Vegetable remains.

In Wisconsin, according to Chamberlin (1877), rocks probably of this age rest on Niagara limestone, and are but sparingly developed. They are overlaid by limestones of the Hamilton group, which, in the absence of intervening beds, rest directly on the Niagara. The greatest thickness recorded for the so-called "Lower Helderberg" rocks of Wisconsin is 7 feet 2½ inches. This is in Fredonia, Ozaukee county, in the bed of Milwaukee river. It is a dolomitic rock, in several layers, some of which are full of *Leperditia alta*. The following species were described from this rock by Whitfield (1882):

Orthis subcarinata Hall.
Orthis oblata Hall.
Meristella (*Whitfieldella*) *nucleolata* (Hall).
Pterinea aviculoidea Hall.
Leperditia alta (Conrad).

The reference of the various Meristoid brachiopods from the western Manlius limestone to Lower Helderberg species of Meristella is open to question. It is much more likely that they all belong to Whitfieldella. To the same genus Whitfield's *Nucleospira rotundata* is probably to be referred. The occurrence of *W. nucleolata* in the Wisconsin Manlius is of interest, this species being otherwise known only from the Coralline limestone of Schoharie county, New York. The great similarities of the faunas of this limestone from Ohio, from Michigan, and from Wisconsin is noticeable, and its close relation to the fauna of the Erie county Manlius limestone is also evident.

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* Rominger, 1896, p. 33.

The identification of the other fossils with Lower Helderberg species of New York may, perhaps, also be questioned, since the imperfect preservation makes absolute determination almost impossible. Even if the determination should be correct, the weight of evidence is in favor of the Manlius limestone rather than Lower Helderberg age of the strata containing these remains. The Lower Helderberg series of rocks, as well as some of the other Devonic beds of New York, are unrepresented in these districts.

A striking piece of evidence of a pronounced unconformity between the Siluric and Devonic strata in northeastern Illinois has recently been described by Weller (1899). He found at the village of Elmhurst that an enlarged joint fissure in the Niagara limestone was "filled with a breccia composed of angular fragments of the adjacent limestone imbedded in a dark brown matrix." This matrix contains an immense number of fish teeth and brachiopods, which indicate the Upper Devonian age of the deposit. Weller deduces from this evidence that "during the greater part of Devonian time the region now known as northern Illinois was above sealevel." He holds that the natural joint fissure was widened through solution by meteoric waters, and that at a later period, near the close of the Devonic, the area was reoccupied by the sea, and the sand and organic remains sifted down into the joint fissure.

THE CONTACT IN ERIE COUNTY

UNCONFORMITY

The upper surface of the Manlius limestone of Erie county is knotty and concretionary, producing minor irregularities. There are also distinct and well marked traces of erosion of these strata prior to the deposition of the overlying rock. These can be seen in the various natural exposures, but are usually best shown in the quarries. Hall * says that—

> "The surface on which the higher limestones rest is very uneven, consisting of abrupt elevations and depressions very similar to the channeled bed of a powerful stream."

The following figures illustrate some of the features of the contact as exposed in the cement quarries in North Buffalo. Figure 1 represents a gentle sag in the beds of the Manlius limestone, an uneven erosion plane truncating the ends obliquely. On this uneven surface rests the Onondaga limestone, which thus has an unconformable relation to the Manlius beds. The length of the section represented is about 10 feet.

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* Hall, 1843, p. 146.

In figure 2 a channeling in the same rock is shown from another part of the quarry. In this channel rests a lens of the Onondaga limestone, followed by regular beds of the same rock.

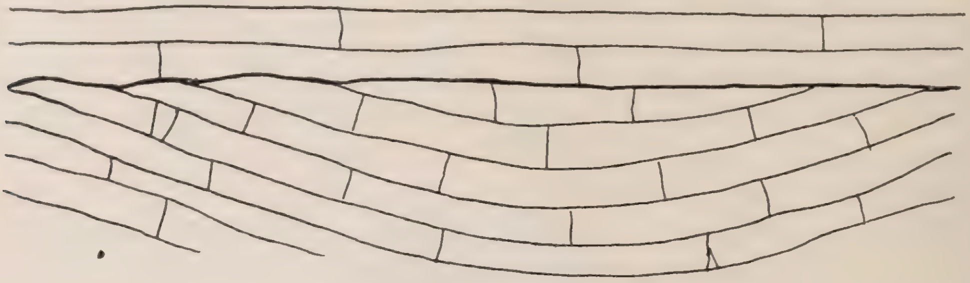


FIGURE 1.—*Sagging and Truncation of Manlius Limestone.*

In figure 3 a number of small channelings in the Manlius limestone are shown, none of which are over a foot in depth. These are filled by lenses of the Onondaga limestone, the whole being overlaid by regular beds of the same rock.

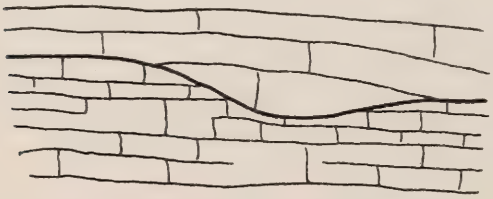


FIGURE 2.—*Channeling of Manlius Limestone.*

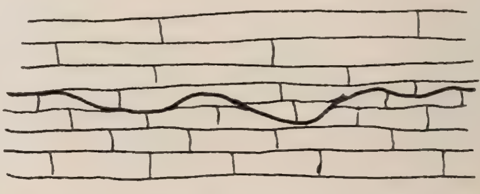


FIGURE 3.—*Channeling of Manlius Limestone.*

In figure 4 a more pronounced case of erosion is shown. This is probably a portion of a broad channel, the other side of which is not exposed. The depth of the excavation is from 3 to 4 feet. The beds of Manlius limestone are horizontal and are cut off obliquely on the left, the depression being filled by thickened lenses of the Onondaga limestone.

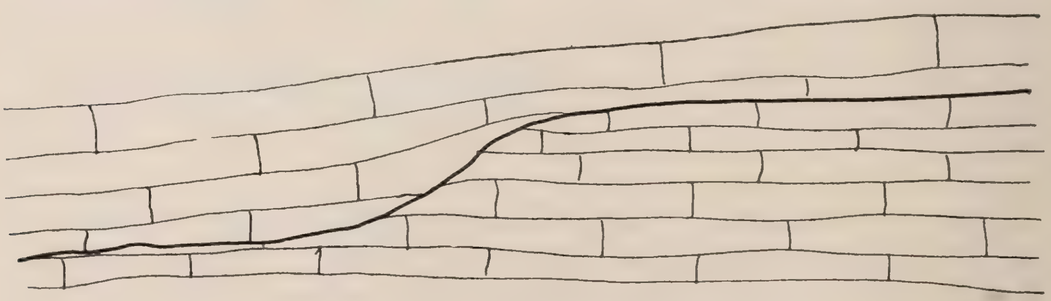


FIGURE 4.—*Erosion of Manlius Limestone.*

In all these cases the contact between the two limestones is either direct or a thin sheet of decomposed shale, the representative of the Oriskany, lies between them.

In figure 5, which represents a section shown in the east wall of the quarry about 2,000 feet south of the stone crusher, the surface of the Manlius limestone is seen to be strongly excavated, the excavation being mainly filled by beds of Onandaga limestone, the chert-free lower portion of which is here about 10 feet thick, while in other portions of the quarry it is only from 2 to 3 feet in thickness. Between the two limestones occurs a mass of shale and conglomerate, having a total thickness in the central portion of something over a foot. The lower 6 or 8 inches consist of a limestone conglomerate, the pebbles being fragments of the underlying limestones, flat, but well rounded on the margins, and showing protracted wearing. They are firmly imbedded in a matrix of indurated quartz sand which surrounds them and fills in all the interstices. This bed thins out to nothing on both sides of the channel. Overlying this conglomerate are about 6 inches of shale and shaly limestone, followed by the Onondaga limestone. The width of the channel is about 18 feet, its depth about 3½ feet.

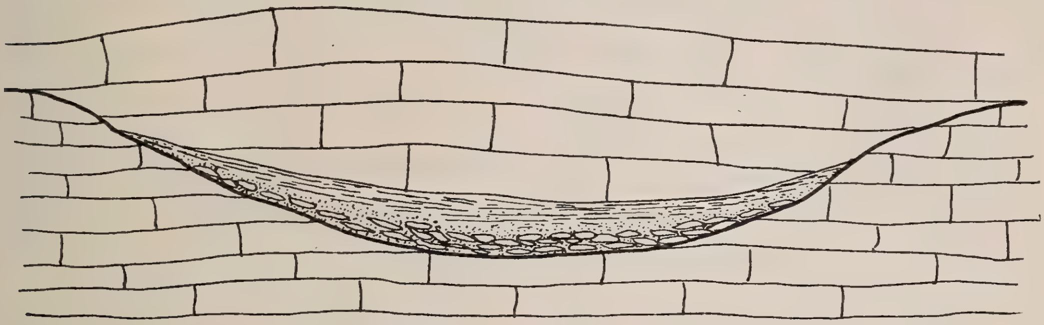


Figure 5.—*Excavation in Manlius Limestone.*

From the point where the channel occurs the contact can be traced continuously for a thousand feet or more eastward in the cliff, showing frequently a thin shaly bed, with here and there grains of quartz sand, between the two limestones.

A SANDSTONE DIKE

In the summer of 1893 the writer's attention was attracted by masses of pure quartz sandstone occurring with the fragments of the Bullhead limestone piled up in the refuse heaps in the cement quarries. Examination showed that this sandstone was intimately associated with the limestone and was not erratic in its nature. On inquiring of the quarrymen, the source of these fragments was found to be a mass of sandstone in the eastern wall of the main quarry somewhat southeast of the mill. The occurrence was designated as a "pocket" by the quarrymen, the quartz sandstone being inclosed on all sides by limestones. A careful examination at a subsequent date showed this so-called pocket to be a residuary dike of sandstone, formed by the filling of a fissure which penetrated the entire thickness of the Bullhead limestone and entered the Rondout Waterlime from 2 to 3 feet. The total depth of the fissure, as now exposed with its filling of sandstone, is in the neighborhood of 10 feet. The dike is squarely cut off at the top, where the Onondaga limestone rests on its truncated end and on the limestones flanking it. The Onondaga limestone is entirely unaffected by the dike, being evidently deposited after the formation and truncation of this remarkable mass of sandstone. The width of the fissure is scarcely anywhere over 2 feet, but lateral offshoots extend for many feet into the walls of Bullhead limestone. These offshoots or rootlets of the dike are irregular, commonly narrow, and often appear as isolated quartz masses in the Bullhead or the Waterlime, the connection with the main dike not being always observable. Such masses of quartz sandstone have been noted at a distance of 20 or 30 feet from the main dike. They are always small. The dike itself has been traced for more than 30 feet in an east-and-west direction in the sloping walls of the quarry. The walls of this ancient fissure are very irregular, angular masses of the limestone projecting into the quartz rock, while narrow tongues of sandstone everywhere enter the limestone. Extensive brecciation of the limestone has occurred along the margin, and the sandstone there is filled with angular fragments of the limestone, which show no traces of solution or wear by running water. These limestone fragments are themselves frequently injected with tongues of the quartz sand, as shown in figure 6.

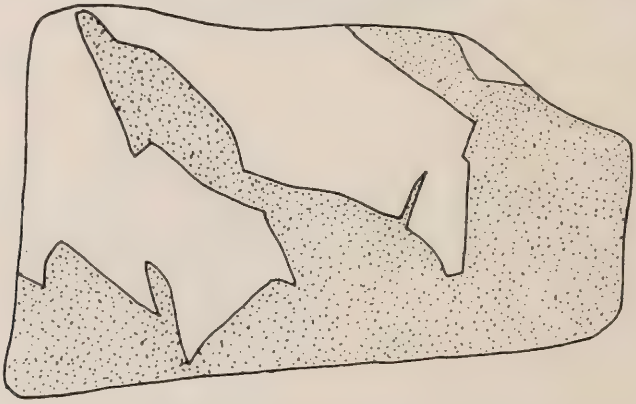
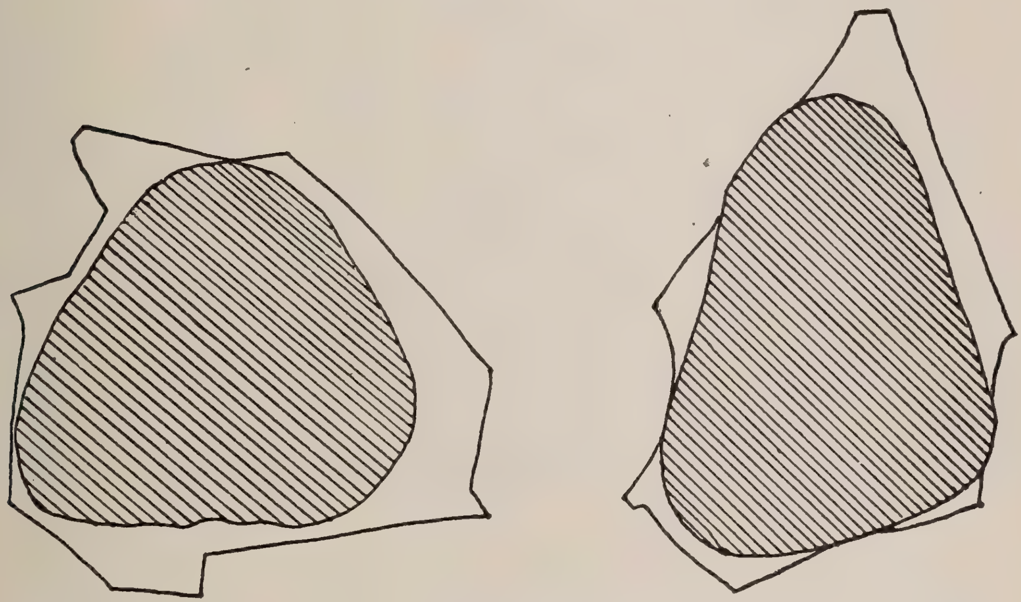


FIGURE 6.—*Fragment of Rock from Margin of Sandstone Dike.*

Showing angular pieces of limestone included in the sandstone and injected by tongues of the sandstone (natural size).

Microscopic examination of the sandstone of the dike shows the grains to be well rounded and closely united by a deposit of secondary silica. Each grain is enveloped by this secondary quartz, which is in optical continuity with the original grain, changing it from a rounded to an angular outline and filling all the interstices. Figures 7 and 8 show such grains of sand, with the secondary quartz unshaded. Viewed in ordinary light, the grain is seen to be outlined by a dark line, and furthermore differentiated from the new quartz by a cloudy appearance, due to numerous inclusions, from which the new quartz is free. This latter is scarcely visible in ordinary light, but with crossed nicols shows a continuation of the colors of the original grain beyond the dark line, which is still visible. The whole extinguishes together.



FIGURES 7 and 8.—*Sand Grains from Dike Enveloped in Secondary Quartz* (*greatly enlarged*).

As seen in section, the enlarged grains have very irregular outlines, with frequent reentrants, occupied by the new quartz of an adjacent sand grain. In the immediate vicinity of an included limestone fragment there is a strong intermingling of the quartz grains with the limestone. The quartz grains retain their original outline, without secondary enlargement, the limestone forming the cement between them. This limestone cement has the same appearance as the solid limestone, being fine grained, granular, and of a grayish color.

Pure calcite is rare, there being apparently little recrystallization from solution, except near the borders of the dike. While the outline of the sand grains is usually sharp, it is not infrequently an irregular one, the limestone matrix appearing as if pressed into the sand grain, thus giving it an irregular border. Individual grains are not infrequently included in a mass of limestone, apparently not differing from the main mass of the limestone. These grains retain their original outline, not showing any secondary enlargement, thus indicating that they were included before the consolidation of the sand in the fissure. The appearance suggests a trituration of the limestone along the walls of the fissure and the borders of the included fragments, the finely granulated limestone mud being mixed with the coarser quartz grains, the whole consolidating without the formation of any but minute crystals of the calcareous minerals. Frequently a considerable mass of the limestone cement occurs between the grains of quartz. and in such cases crystals of pure calcite or dolomite occur in the center of the cement.

Sometimes sand grains are only partially surrounded by limestone, the other portions showing an addition of secondary quartz. Occasionally the interstices between adjoining sand grains are completely filled by new quartz of definite form and individualized. Along the contact zones between sandstone and limestone, cavities occur in the latter rock, completely filled with crystalline calcite, indicating a recrystallization after the disturbance which granulated the limestone. There are also microscopic fissures in the limestone masses filled with crystalline calcite. Along the sides of the dike, masses of limestone in long narrow bands are not uncommon in the quartz rock. These commonly contain rounded sand grains, and near their margins the grains of the dike are surrounded and cemented by the limestone. They appear to represent crushed masses of limestone, which were strung out parallel to the walls of the fissure while the sand was in motion. Carbonaceous matter is common in these limestone bands and the limestone adjoining the quartz dike generally. It usually occurs in black specks, which are numerous where the limestone shows evidence of crushing, but much less common in the solid, unaltered limestone. Sometimes the quartz grains of the dike near the margin are entirely surrounded by the carbonaceous matter, which in places constitutes the cement.

All the features, macroscopic and microscopic, which accompany the sandstone dike point to a cataclysmic origin of the fissure which contains it and a more or less violent injection of the sand. Mere erosion or widening of a joint fissure by solution will not account for the phenomena observed. That the fissure was formed before the deposition of the Onondaga limestone seems evident from the fact that this latter rock is entirely unaffected. It seems also certain that the fissure was formed after the deposition of a considerable mass of sand over the Manlius limestone, and that the formation of the fissure and the injection of the sand from above occurred simultaneously. In no other way can we account for the inclusion of horses of the wall rock, often of considerable size, and the injection of the sand into all the fissures and crevices; nor can we readily explain on any other hypothesis the trituration of the limestone along the borders, which clearly indicates a violent contact between the sand and the already consolidated limestone. The supposition that the fissure is due to a violent disruption of the wall, probably the effect of an earthquake shock, is further borne out by the numerous minute faults which occur in the Waterlime in the vicinity of the fissure and elsewhere. These faults never exceed in throw a fraction of an inch, and are only brought out by the very perfect banding of the Waterlime.

From the fact that the sand which filled the fissure is not traceable along the contact away from the fissure, except in a very thin interrupted bed, in which shaly limestone predominates, and sand grains are not very plentiful, indicates that some considerable erosion may have occurred after the filling of the fissure, for it is hardly conceivable that all the sand deposited on the surface of the limestone should have been injected into the fissure. It is much more likely that a considerable bed of sand had accumulated above the Bullhead, part of which was forced into the fissure when it was produced. The remaining sand, as well as that covering the limestone away from the fissure, must have been swept away subsequently, only thin residual lenses remaining in hollows of the underlying rock. Indeed, it is not improbable that the Bullhead limestone was formerly much thicker, and that the dike extended higher up, an indeterminable thickness of limestone and dike having been removed by erosion during early Devonic times.

Devonic Rocks adjoining the Contact in Erie County

ORISKANY REPRESENTATIVE

Since Schuchert (1900) and Clarke (1900) have demonstrated that the Helderbergian rocks, from the Coeymans (Lower Pentamerus) limestone to the Kingston (Upper Shaly) beds, inclusive, are, from the nature of their faunas, referable to the Lower Devonian, it is evident that the Siluric section has its best representation in western New York, where all its members from the Medina sandstone to the Manlius limestone are developed. Not so, however, in the case of the Devonic; practically the whole of the Lower Devonian and a great part of the lower Middle Devonian (following Clarke and Schuchert's classification, 1899) are unrepresented. The whole of the Helderbergian series of rocks is wanting, as well as the Esopus and Schoharie grits. The only representation of the Lower Devonian is in the thin beds of shale, shaly limestone, sand, and conglomerate already noted as occupying hollows in the surface of the Manlius limestone. Clarke holds that the region about western New York was dry land, or at least not much below sealevel, during all the time that the Lower Devonian rocks were accumulating in eastern New York. I fully agree with this view, and from evidence given above it appears that this condition extended westward.

No fossils have been found in the bed supposed to represent the Oriskany, and this identification, based only on the position of the rock, is not to be considered as strictly correct. These accumulations of shale, sandstone, and conglomerate may have occurred at any time during the long interval marked by the accumulation of the Helderbergian, Oriskanian, and Lower Ulsterian rocks in eastern New York and the development of their faunas. These thin intermediate beds bear no necessary time relation to the Oriskany sandstone of central and eastern New York, and they are correlated with this horizon merely on stratigraphic evidence.

These intermediate beds are not restricted in occurrence to the region about North Buffalo. Hall* states that in the eastern portion of the county—

> "In the town of Newstead a mass of partially decomposed clay and sand lies between the Waterlime and Onondaga limestone; it is about six inches or a foot thick, highly stained with iron, and exhibiting a partially conglomerated appearance. In this are several peculiar coralline fossils. It occupies the place of the Oriskany sandstone, and is its only representative."

The fossils have never been described and their affinities are unknown.

ONONDAGA LIMESTONE

This is the only representative of the lower Middle Devonian (Ulsterian of Clarke and Schuchert) in western New York, both the Esopus (Cauda-galli) and Schoharie grits being absent. The lower portion of this limestone is crystalline and free from chert, commonly highly fossiliferous and varying greatly in thickness. In the cement quarry in North Buffalo it is usually 2 to 3 feet thick, except above the thin stratum of conglomerate, the thickness there being nearly 10 feet, decreasing rapidly on all sides. On Skajaquada creek, Bishop gives its thickness as 3 to 5 inches at the Main Street bridge and 7 feet in Forest Lawn cemetery. In the Park quarry it is 5½ feet thick, while at Fogelsonger's quarry, in Williamsville, it has a thickness of 35 feet. "At Young's quarry, 2 miles farther east, it is 30 to 35 feet thick, but thins out rapidly beyond to a thickness of 3 to 5 feet."† At the two quarries last mentioned the rock is chiefly a mass of coral, the remains of an ancient coral reef.

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* Hall, 1843, p. 472.

† Bishop, 1895, p. 313.

The Corniferous limestone, which is now included with the Onondaga, of which it constitutes the upper cherty beds, is well developed throughout Erie county, forming the summit rock of the cuesta. The average total thickness of the Onondaga limestone (including both the Corniferous and the Crystalline beds) is given by Bishop (page 390) as 108 feet in Erie county. The whole of this, however, is not shown on the edge of the cuesta, erosion having removed a great part of the upper beds. The thickness has been obtained from well borings near the southern edge of the outcrop.

Stratigraphic Summary

The Siluric section is complete in Erie county, New York, from the Medina sandstone to the Manlius limestone, which in New York state is the upper member of the Siluric. An important, though not very readily noticed, unconformity exists between the Manlius limestone and the overlying Onondaga limestone of the lower Middle Devonian. This unconformity indicates a period of land surface in western New York, during which the Lower Helderberg and Oriskany beds and the Esopus and Schoharie grits were deposited in the east. Thin deposits of a conglomerate and shaly sand and limestone occasionally occur in hollows in the eroded surface of the Manlius limestone. These may be considered Oriskany, though their age may be anywhere in the Lower Devonian. A remarkable fissure in the Siluric rocks and bearing evidence of being formed by violent action is filled with pure quartz sandstone containing angular limestone fragments. This was formed and filled before the deposition of the overlying Onondaga limestone. In Ohio and Michigan the Manlius limestone is a brecciated, often conglomeritic limestone, bearing strong evidence of shallow water and at times dry land. The fauna of the Manlius limestone in Erie county is a recurrence of the fauna of the Coralline limestone, the Niagara equivalent of Schoharie county.

Synopsis of the Organic Remains in the Manlius Limestone of Erie County

NEMATOPHYTON CRASSUM PENHALLOW

1896. *Nematophyton crassum* Penhallow. Canadian Record of Science, July 1896, pages 151–156, plate II.

This species was identified by Penhallow from a specimen obtained by Mr F. K. Mixer from the upper part of the "Waterlime group" in Buffalo. The specimen came from the Bullhead or Manlius limestone of the Buffalo cement quarry. A detailed description with illustrations of transverse sections is given by Penhallow.

CYATHOPHYLLUM HYDRAULICUM SIMPSON

(Plate 21, figures 1*a–d*.)

1900. *Cyathophyllum hydraulicum* Simpson (MSS.). Memoir of the New York State Museum. "The Genera of Palæozoic Corals." (In press.)

Corallum simple, conico-cylindrical, usually long and slender. Growth irregular, with numerous abrupt changes in direction. Surface of the mature portion longitudinally ribbed by numerous rounded costal ridges, which are strongly marked and separated from each other by a sharply depressed line. Epitheca well developed, the numerous lines of growth strongly marked on the surfaces of the costæ. The epitheca is thrown into frequent coarse wrinkles which give the coral a very rugose appearance.

The young corallum is usually destitute of costæ, and is subcylindrical in form, barely increasing in diameter through a length of over half an inch. It is strongly marked by the wrinkles and lines of growth of the epitheca, which are sometimes quite sharp. At the end of this youthful stage the corallum rapidly expands, often abruptly so, and the costæ quickly become prominent.

Calyx of moderate depth, the total depth being usually somewhat less than the greatest diameter of the calyx. Septa numerous, strong but thin, and separated by interspaces from two to three times their width. They retain a uniform width from periphery to center. Bottom of calyx often flattened in the center; the septa meet and become slightly twisted. They not infrequently unite before they reach the center. Dissepimental structures appear to be well developed. No fossula occurs.

The corallum is not infrequently curved, the primary septum then appearing on the convex side. The remarkable cylindrical, non-costate young with strongly wrinkled epitheca, and the usually abrupt appearance of the costæ, and the concomitant rapid expansion of the corallum are the most striking features of this coral. No internal structure has been observed, as the fossils are nearly all represented by hollow molds. From these, gutta-percha casts can readily be made which will show all the external characters of the corallum in great clearness. No well preserved coral has been found so far, the only cases where the coral was preserved at all being rendered worthless by the crystallization of the whole interior, thus destroying all structural features.

These corals are abundant in the upper three or four feet of Manlius limestone in nearly all its exposures in Erie county. Most of the individuals lie parallel to the bedding plane, having fallen before they were buried. No specimens are known from localities outside of the county.

ORTHOTHETES HYDRAULICUS (WHITFIELD)

(Plate 22, figures 1*a-c*.)

1882. *Streptorhynchus hydraulicum* Whitfield. Annals of the New York Academy of Sciences, volume ii, page 193; volume v, 1891, page 508, plate 5, figures 1–3.

1893. *Streptorhynchus hydraulicum* Whitfield. Report of the Geological Survey of Ohio, volume vii, page 410, plate I, figures 1–3.

This species, originally described from Bellville and Greenfield, Ohio, is abundant in the Manlius limestone of Erie county. The shell is rarely preserved, but the molds are often very perfect, allowing sharp and clear gutta-percha casts to be taken.

The pedicle valve has a slightly elevated beak, with a low, triangular cardinal area, which is flat and transversely striate; delthyrium moderate, covered in great part by a strong convex deltidium. The cardinal teeth are prominent and supported by two short and narrow dental plates, which have the same angle of divergence as the sides of the delthyrium. The cardinal extremities are obtuse, the hinge line being shorter than the greatest width of the shell, while the front is uniformly rounded.

The brachial valve has a very narrow hinge area, which is erect, making a moderately obtuse angle with the hinge area of the pedicle valve. A strong band-like chilidium covers the median fissure. Between it and the deltidium there is a narrow open space, through which can be seen the cardinal process, which appears bilobed; surface of both valves marked with strong, rounded, but sharply defined radiating striæ, which curve slightly upward on the lateral margins near the cardinal area. The strongest of these reach close up on to the beak. Passing forward, new striæ appear between them as soon as they have separated by more than their own width. Additional sets of striæ appear as the shell increases in size, these having been observed up to the fifth generation. The striæ are cancellated by uniform, close, fine, and regular concentric lines, which are most prominent on the striæ.

A mold of the interior shows the striæ quite strongly, and even the cancellations are visible. It is not improbable, however, that after the solution of the shell, the two molds becoming closely appressed, the stronger external features were impressed upon the weaker internal, thus accounting for the markings, which would otherwise indicate a shell of great tenuity. The muscular impressions have not been retained in the molds.

This species is so closely related to *Orthis* (*Orthothetes*) *interstriatus* Hall, of the Coralline limestone at Schoharie, that it is practically impossible to distinguish the two. In size, outline, and convexity of valves, form, and method of intercalation of striæ and character of cancellating lines, the specimens from the Manlius limestone of Erie county and those of the Coralline limestone of Schoharie county appear to be identical. The only difference observed is in a shallow but broad mesial depression in the pedicle valve which occurs in a number of specimens from Williamsville and Akron, but has not been observed in the Coralline limestone species; neither does it always or even very commonly occur in the Manlius limestone species in Erie county, New York. It appears to be characteristic of the specimens of this species from Ohio.

This species occurs throughout the Manlius limestone in Erie county, but is most abundant in the upper 2 or 3 feet. Sometimes slabs of the stone are covered with the impressions of these shells, one mold obliterating the other. Similar conditions occur in this rock at the Ohio localities.

SPIRIFER ERIENSIS, SP. NOV.

(Plate 21, figures 2*a*–*b*.)

Shell small, pedicle valve strongly convex, almost ventricose, subrhomboidal in outline, with the beak much elevated and gently incurved. Mesial sinus pronounced; angular in the center, with the sides nearly flat, gradually and uniformly increasing in width from the beak forward. Sometimes it is slightly rounded in the bottom. It is prolonged at the front of the shell as a prominent rounded lip. On either side of the sinus is a moderately strong, broadly rounded, but not very prominent plication, in addition to which there are about three or four on either side, which are fainter and progressively become narrower away from the sinus. Interspaces narrow, having the form of a depressed line, the broadest next to the plication adjoining the sinus. Brachial valve almost semicircular, moderately convex, with a straight hinge line, which is shorter than the greatest width of the valve. Beak elevated above the hinge line and incurved. Fold distinctly defined by a sharp depressed line on either side, but not elevated much above the general surface of the valve. It gradually and uniformly widens forward, is broadly rounded on top, and is occasionally marked by a slight central depression. Ribs almost obsolete, a faint depression outlining the first on either side of the fold in some specimens. Surfaces of both valves marked by fine, uniform, and subequally spaced concentric lines which curve forward in the sinus of the pedicle valve. Occasionally strong lines mark a temporary resting stage during growth. The whole surface appears to be covered with fine radiating striæ, which are interrupted by the concentric striæ, thus giving the surface a fimbriate appearance.

On the interior of the pedicle valve are two short dental plates, diverging slightly more than the sides of the sinus.

The cardinal area of this species is high, occupying in some specimens as much as a third of the total height of the valve. The strength of the ribs on the brachial valve varies somewhat in different specimens, but they are always much less marked than those of the pedicle valve, and they are usually quite obsolete.

The species to which this most nearly approaches is the variety of *S. crispus* Hisinger found in the Coralline limestone at Schoharie. In this variety the ribs are much fainter than in the normal *S. crispus* of the Niagara shales and limestones of western New York. In many specimens from Schoharie the ribs are almost obsolete. comparing well with their character in *S. eriensis.* The sinus of the Schoharie specimens is subangular, and the fold flattened much as in the Bullhead limestone species. This variety is also proportionally higher than the normal form, giving a subrhomboidal outline to the pedicle valve, which strongly recalls *S. eriensis.* In general the ribs of this latter species are slightly broader and rather more flattened on top than is the case in the Coralline limestone species, and the interspaces are somewhat narrower. Taking all the variations into consideration, a very close relation must be accepted as existing between the two species.

The specimens described by Whitfield as *S. vanuxemi* from the hydraulic limestone (Manlius?) of Peach point, Put-in-bay, Lake Erie, resembles rather more closely the normal *S. crispus* than it does the typical *S. vanuxemi* of the Manlius limestone of central New York. This similarity to the Niagaran species was observed by Whitfield. The strong plications and greater width separate it from *S. eriensis.*

Most of the specimens of *S. eriensis* were found at Williamsville. A few, however, came from the cement quarries in North Buffalo.

Width of the pedicle valve illustrated, 10 millimeters; length, 8.5 millimeters. Width of the brachial valve illustrated, 7.5 millimeters; length, 6 millimeters.

WHITFIELDELLA SULCATA (*VANUXEM*)

(Plate 22, figures 2*a–d*.)

1842. *Atrypa sulcata* Vanuxem. Geological Report of the Third District of New York, page 112, figure 5.

1843. *Atrypa sulcata* Hall. Geological Report of the Fourth District of New York, page 142, figure 5.

1859. *Merista bisulcata* Hall. Paleontology of New York, volume 3, page 253.

This characteristic Manlius limestone species is quite common in the Bullhead limestone of North Buffalo and Akron. The individuals are of the size of the specimens figured by Vanuxem and Hall and agree closely with them in form and proportions.

The shell is ventricose, elongately ovoid to subpentagonal in outline, most bulging in the posterior third. The beak of the brachial valve is slightly incurved and overarched by that of the pedicle valve, which is considerably more elevated. The mesial sinus of the pedicle valve is well developed, narrow and prominent near the front; that of the brachial valve is less prominent, being more of the nature of a flattening near the anterior margin. The concentric lines of growth are very fine and occasionally interrupted by strong wrinkles. Near the front of the pedicle valve in mature or senile individuals an abrupt change of growth occurs, the relative size of the valve becoming progressively reduced with further growth. On this portion of the shell the lines of growth are more prominent.

This shell is readily recognized by its elongate character, strong ventricosity, and well marked sharp mesial sinus in the pedicle valve. It is not uncommon in the more compact portions of the rock, but in the porous portions it appears usually as hollow molds.

The measurements of an average pedicle valve are: Length, 9.5 millimeters; width, 7.5 millimeters; convexity, 3.5 millimeters.

WHITFIELDELLA CF. ROTUNDATA (WHITFIELD)

(Plate 22, figures 3*a-b*.)

Compare *Nucleospira rotundata* Whitfield. Annals of the New York Academy of Sciences, volume ii, 1882, page 194, and Geological Survey of Ohio, 1893, volume vii, page 413, plate I, figures 11-14.

Shell small, subcircular in outline, with the valves moderately convex; pedicle valve more strongly convex than brachial, slightly longer than wide, with a pointed, gently incurved, and slightly overhanging beak. The greatest convexity of the valve is a little posterior of the center, from which point the contour descends toward the beak, at first with a gentle, then with a more abrupt curvature. The final portion of the curve of the beak is approximately at right angles to the plane of contact between the valves. Anteriorly the slope is a uniform curve. A faint medial flattening or depression occasionally occurs; rostral cavity deep; teeth supported by short, strongly diverging dental lamellæ, which appear to lie just beneath the cardinal slopes; surface marked by numerous lines of growth and by frequent (in some specimens) stronger concentric wrinkles; brachial valve less convex than the pedicle, with the beak closely incurved beneath that of the pedicle valve. In some specimens the cardinal slopes are less rounded, giving the posterior portion of the shell a subtriangular aspect.

The subcircular expression of the shell, its moderate and uniform convexity, and the gently incurved beak distinguish this species. It may most readily be compared with Whitfield's *Nucleospira rotundata* from Greenfield, Ohio, but that species is usually represented by larger specimens.

A comparison with *Whitfieldella nucleolata* Hall of the Coralline limestone of Schoharie shows considerable similarity between the two species. The Coralline limestone species has, however, a more circular expression, the width usually slightly exceeding the length. In other respects the two species are very close. This species is not uncommon in the friable bituminous portion of the Manlius limestone at Akron, in the extreme eastern portion of Erie county, New York. It has so far been found chiefly in the form of molds, both external and internal, the shell being wholly dissolved. Characters of the exterior are often impressed on the internal mold from pressure contact. Occasionally the mold is filled with crystalline calcite, which forms a perfect cast of the shell.

An average pedicle valve measures 9 millimeters in length by 8 millimeters in width. The convexity of the valve is 2.5 millimeters.

WHITFIELDELLA CF. LÆVIS (*WHITFIELD*)

(Plate 22, figures 4*a-d*)

Compare *Meristalla lævis* Whitfield. Annals of the New York Academy of Sciences, 1882, volume ii, page 195; ibidem, Geology of Ohio, volume vii, 1893, page 411, plate I, figures 6–7.

Compare *Meristella lævis* (Vanuxem) Hall. Palæontology of New York, volume 3, plate 39, figure 1.

Not *Atrypa lævis* Vanuxem. Geological Report of the Third District of New York, 1842, page 120, figure 2.

Shell small, the largest specimen obtained not exceeding 10 millimeters in length. Pedicle valve broadly ovoid, gibbous, the greatest gibbosity in the umbonal third. Longitudinal contour a symmetrical curve, descending more abruptly in the umbonal region. Transverse contour, a symmetrical arch flattened at the top, and with steep sides, which approach verticality in the umbonal region. A faint depressed line runs down the center from near the beak to the anterior margin. Surface marked by fine concentric growth lines and by coarser wrinkles appearing at intervals.

Rostral cavity of moderate depth; teeth strong and rounded, supported by two thin but prominent dental lamellæ which diverge but slightly and arise from the bottom of the valve. Beak apparently truncated by a circular foramen of moderate size. A strong, rather broad, and not distinctly defined median elevation divides the muscular area, which appears to be longitudinally striate. This ridge broadens forward and at the same time becomes more and more obsolete. The rostral portion of the pedicle valve of this species is strongly compressed laterally, the sides converging uniformly. This gives the shell an elongate appearance, while the actual length is but slightly greater than the width. There is some variation in this, in some cases the length being scarcely more than the width.

Brachial valve somewhat less convex than pedicle, with the beak incurved beneath that of the pedicle valve.

The ovoid form, very slightly diverging dental lamellæ, and the median ridge dividing the muscular impression distinguish this species from the preceding one.

RHYNCHONELLOID

A single fragment has been found of a coarsely and angularly ribbed brachiopod, with the ribs anteriorly incised for the reception of those of the opposite valve. The ribs are too large and too angular to allow reference to Whitfield's *Rhynchonella hydraulicum*, from similar rock of Greenfield, Ohio. In this latter species the ribs are rounded on top and they are less coarse. The specimen was obtained at Akron, New York, and is replaced by calcite.

LOXONEMA ? SP.

(Plate 22, figure 5.)

An internal mold showing nothing but the general outline of the volutions and the form of the spire was obtained from the Manlius limestone of Buffalo. Only four volutions remain, separated by rather deep sutures. Whorls uniformly rounded. Angle of divergence between 11 and 12 degrees. From the imperfect state of preservation, even the generic determination must be doubtful.

PLEUROTOMARIA ? SP.

A trochiform gastropod, perhaps referable to this genus, was obtained from the Manlius limestone of Buffalo. The specimen is very poorly preserved, only partial molds remaining. The volutions, of which there appear to have been 5 or 6, are rather low and somewhat flattened, with apparently an angulation on the margin. The shell appears to have been umbilicated.

TROCHOCERAS GEBHARDII HALL

(Plate 21, figures 3*a–b*.)

1852. *Trochoceras gebhardii* Hall. Paleontology of New York, volume 2, page 335, plate 77, figure 2; plate 77*A* figures 1*a–d*.

This species, originally described from the Coralline limestone of Schoharie county, is represented by several specimens from the Manlius limestone of Erie county. A very perfect specimen (plate 21, figures 3*a–b*) obtained by Vogt and Piper from the cement quarries, preserves about 4½ volutions, several being broken away at the apex. The shell has the aspect of a large gastropod with rounded, strongly embracing whorls. The umbilicus is wide and deep, the margin angular, cross-section of body whorl irregularly subhemispherical. The apical angle of the spire is 60 degrees, the sutures being moderately depressed below the outline. No septa are shown. In a specimen from Williamsville, referred to this species, the surface of the shell is marked with fine crowded lines of growth. No other surface ornamentation is shown.

Greatest diameter of the spire of the illustrated specimen, 75 millimeters. This is about a volution younger than the type specimens, with which it agrees in all the points which admit of comparison. Where the body whorl has a height of 45 millimeters, the umbilicus has a diameter of 30 millimeters.

In addition to the fine specimen obtained from Buffalo, a number of compressed portions of whorls have been obtained from this rock at Williamsville. These are in the state collection at Albany and appear to represent older and larger individuals. The fact that septa are not visible does not render the identification doubtful, as the form of the shell is very characteristic. The greater portions of the type specimens from Schoharie show no septa.

LEPERDITIA SCALARIS JONES

(Plate 22, figures 6*a–d*.)

1858. *Leperditia gibbera* var. *scalaris* Jones. Annals and Magazine of Natural History, third series, volume iv, page 250, plate x, figures 7*a–b*, 10*a–b*, 11.

This species was described by Jones from specimens obtained from the gray "Waterlime rock" of Williamsville by Sir Charles Lyell. One of his specimens was half an inch in length by three-tenths of an inch in height. The species is confined to the Manlius limestone in Erie county, and occurs, besides at Williamsville, at Buffalo and Akron. It is usually very common, often crowding the surface of the thin layers of limestone. The general outline of the carapace is bean-shaped, as in Leperditia generally. The greatest height is posterior to the middle. Hinge line straight, about two-thirds the length of the carapace, terminating anteriorly in an obtuse, slightly salient angle. Posterior extremity of hinge line likewise salient, with the posterior border below it uniformly rounded on a short radius. Anterior dorsal margin sloping off abruptly, making an angle of about 130 degrees with the hinge line. Anterior end nasute, obtusely rounded. Basal margin a uniform but asymmetric curve, more convex in the posterior portion of the shell. A distinct marginal border or fold occurs on both anterior and posterior ends, the former being the stronger and best defined. It is well flattened, with the margin sometimes slightly elevated. Ocular tubercle about a third the length of the carapace from the anterior end and about a fourth of the height below the dorsal margin. The longitudinal contour is a flattened curve, rather more convex in the anterior third and becoming abrupt near the ends. Dorso-ventral contour an asymmetric curve, flatter near the hinge line and abruptly incurved at the ventral border. The ventral border of the right valve overlaps that of the left valve, which is abruptly flattened.

In the left valve occurs a strong, elongated fold or nodule, situated just below the hinge line in the posterior half of the carapace. It begins about midway of the length of the hinge line and extends backward to half way between the center and the posterior end, thus equaling in length about a fourth of the hinge line. This fold is accentuated by an abrupt depression of the valve below it, the fold thus becoming strongly pronounced below, but grading into the upper slope of the valves. This fold or "dorsal hump" is wanting in the right valve. Surface smooth. A perfect right valve measures: Length, 11.5 millimeters; height, 7.5 millimeters; hinge, 9 millimeters; greatest convexity, 2.5 millimeters. Another measures 12 by 7 millimeters, with hinge line 8 millimeters long. Another measures 11.5 by 6.5 millimeters. Three left valves from Williamsville measure respectively 10.5 by 5.5 millimeters, 9.2 by 5 millimeters, and 8.5 by 4.5 millimeters.

Specimens of similar form occur, according to Jones, in the black limestone of the "Scalent group" of Pennsylvania. The left valve has a distinct small dorsal hump, the right valve being without it.

This species recalls in form and size *L. jonesi* Hall of the Coralline limestone of Schoharie. No dorsal hump has been described or figured for this species, but Jones says:*

---

* Annals and Magazine of Natural History, 5th series, vol. 14, p. 343.

"A specimen of '*L. jonesi*' [from the Waterlime of the Lower Helderberg] in the American Museum of Natural History at New York I have observed to have not only a reticulate muscle spot [characteristic of well preserved specimens of the species], but also to be somewhat gibbous on the postero-dorsal margin of the left valve."

If the dorsal hump exists in *L. jonesi*, another link is established in the relationships between the faunas of the Coralline limestone and the Manlius limestone of Erie county.

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EXPLANATION OF PLATES*

PLATE 21.—*Manlius Limestone Fossils, Erie County, New York*

(All are natural size except figures 2*a-b*, which are × 2)

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FIGURE 1*a–d*. *Cyathophyllum hydraulicum* Simpson.......................... 364

1*a*. Showing slender cylindrical youthful stages, free from costæ.
1*b*. A normal individual with the young stages broken away.
1*c*. An uncommonly regular individual, showing strong costæ.
1*d*. Calyx.
(After Simpson, drawn from gutta-percha casts)

FIGURE 2*a–b*. *Spirifer eriensis* Grabau...................................... 366

2*a*. Pedicle valve × 2.
2*b*. Brachial valve of a smaller individual × 2.

FIGURE 3*a–b*. *Trochoceras gebhardii* Hall.................................... 371

3*a*. Side view, showing the spire.
3*b*. Umbilical view.

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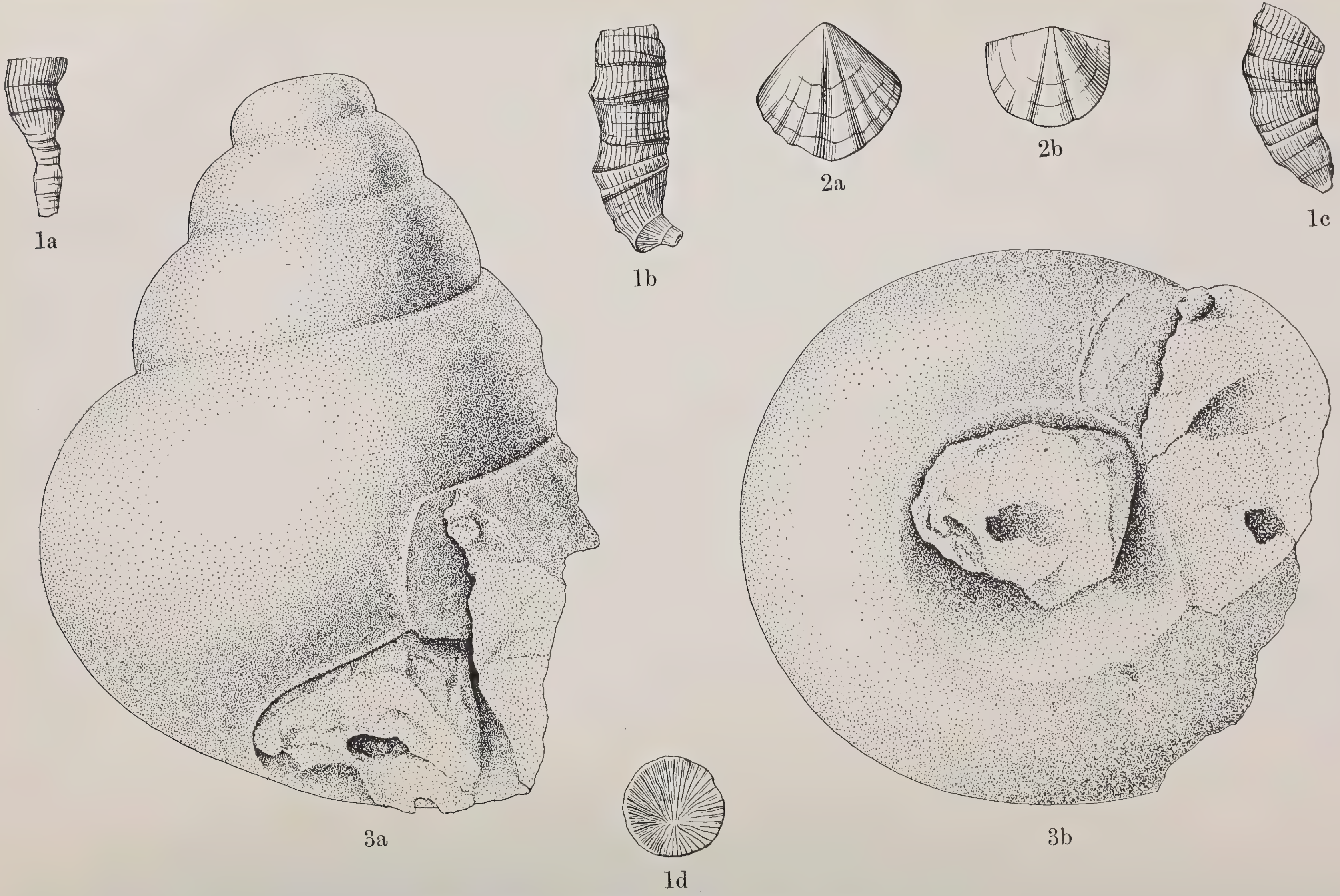
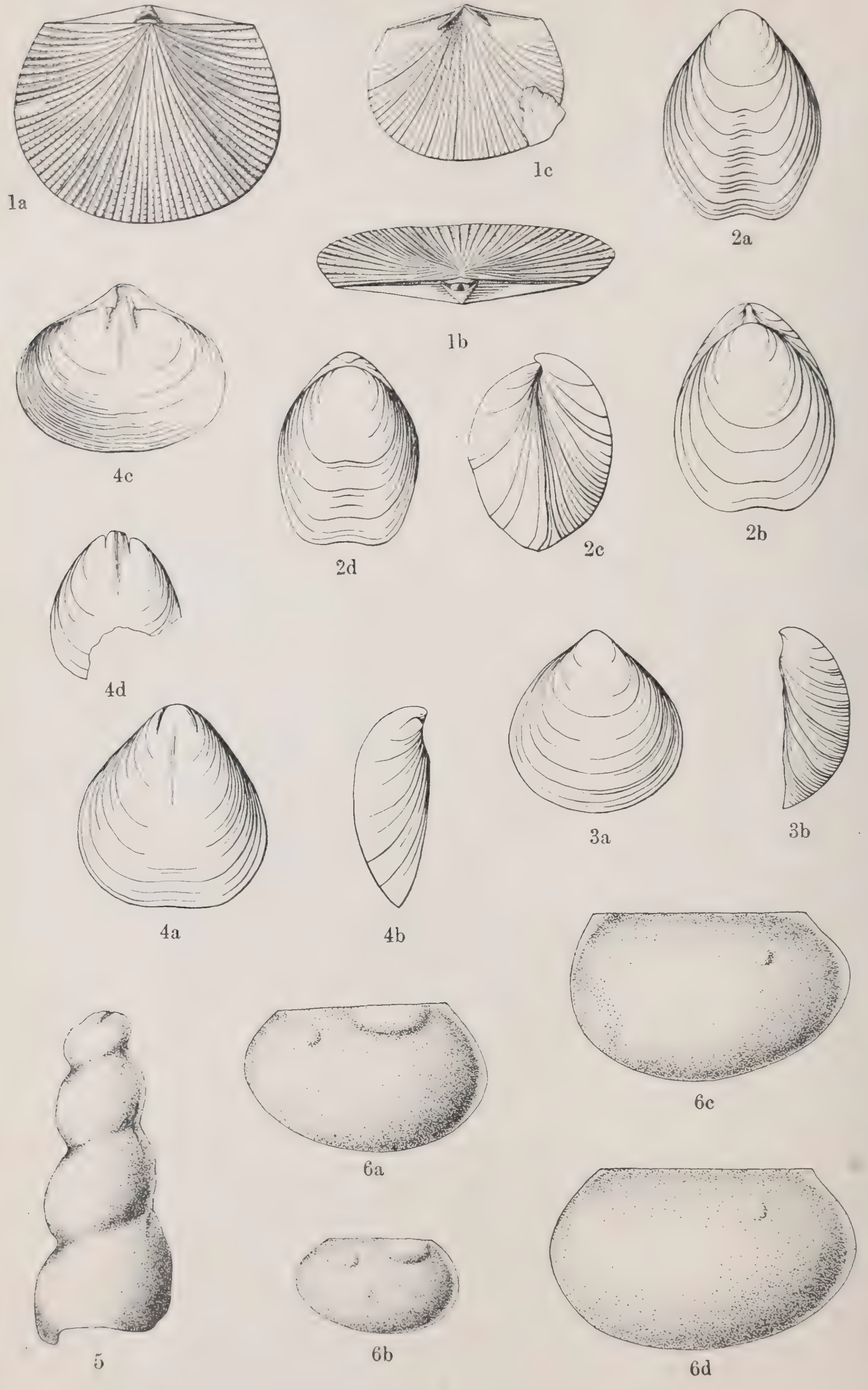
* The fossils were drawn by Miss Elvira Wood, instructor of paleontology in the Massachusetts Institute of Technology.



MANLIUS LIMESTONE FOSSILS, ERIE COUNTY, NEW YORK



MANLIUS LIMESTONE FOSSILS, ERIE COUNTY, NEW YORK

PLATE 22.—*Manlius Limestone Fossils, Erie County, New York*

(All are enlarged × $2\frac{2}{3}$ except figure 1*b*, which is enlarged × $3\frac{1}{3}$)

Page

FIGURE 1*a–c*. *Orthothetes hydraulicus* (Whitfield)............................... 365

1*a*. View of the brachial valve, with the hinge area of the pedicle valve, showing deltidium.

1*b*. View of the same from above, showing hinge areas of both valves, the strong deltidium of the pedicle valve and the bifid cardinal process and band like chilidium of the brachial valve. (× $3\frac{1}{3}$.)

1*c*. View of the interior of a smaller pedicle valve, showing cardinal teeth and dental plates.

(All are drawn from gutta-percha casts)

FIGURE 2*a–d*. *Whitfieldella sulcata* (Whitfield)............................... 367

2*a*. View of a pedicle valve, showing the mesial sinus. The specimen also shows old age characters. The shell is retained in this specimen.

2*b*. Another specimen showing brachial valve and the cardinal slopes of the pedicle valve. The foramen and delthyrium are somewhat imperfect.

2*c*. Lateral view of a specimen.

2*d*. Dorsal (brachial) view of the same.

(2*b*–2*d* are drawn from gutta-percha casts and are slightly restored)

FIGURE 3*a–b*. *Whitfieldella* cf. *rotundata* (Whitfield) 368

3*a*. View of a pedicle valve, the shell having been dissolved and the mold of the exterior impressed on that of the interior.

3*b*. Side view of same, showing position of dental plates.

FIGURE 4*a–d*. *Whitfieldella* cf. *lævis* (Whitfield)............................... 369

4*a*. Internal mold of pedicle valve, showing impressions of dental plates.

4*b*. Side view of same.

4*c*. Cast of same in gutta-percha, showing cardinal teeth and dental plates. (The drawing is foreshortened.)

4*d*. Another internal mold of a pedicle valve, showing impressions of dental plates and median septum.

(4*c* is drawn from a gutta-percha cast)

Page

FIGURE 5. *Loxonema ?* sp. 370

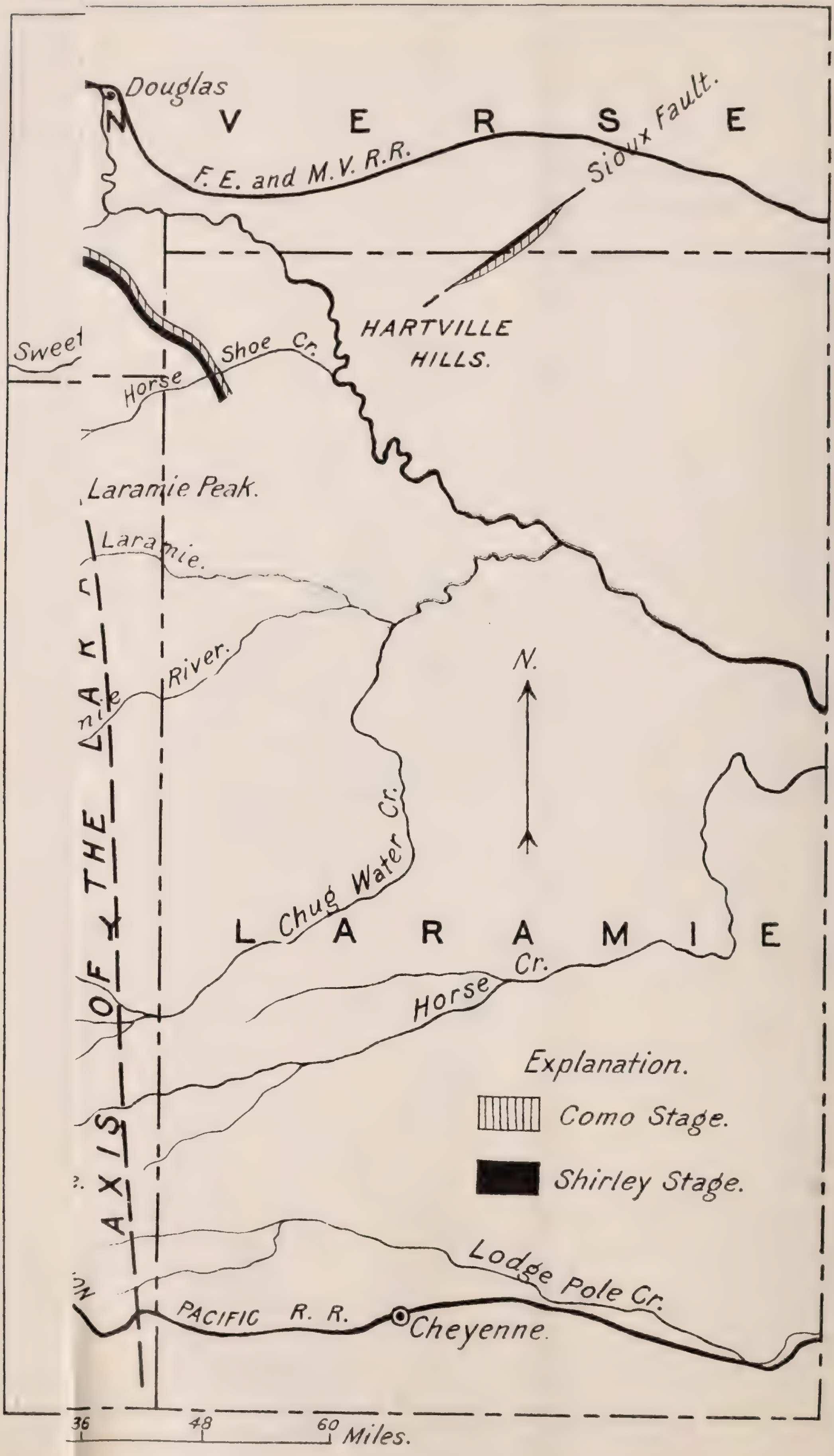
An internal mold in the rock matrix.

FIGURE 6*a–d*. *Leperditia scalaris* Jones 371

6*a*. Left valve, showing ocular tubercle and dorsal nodule.

6*b*. A smaller left valve, showing an additional subcentral tubercle (muscle-spot ?).

6*c–d*. Two right valves, showing eye tubercle and marginal flattening.



\ SOUTHEASTERN WYOMING

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JURASSIC ROCKS OF SOUTHEASTERN WYOMING

BY WILBUR C. KNIGHT

(*Presented before the Society December 29, 1899*)

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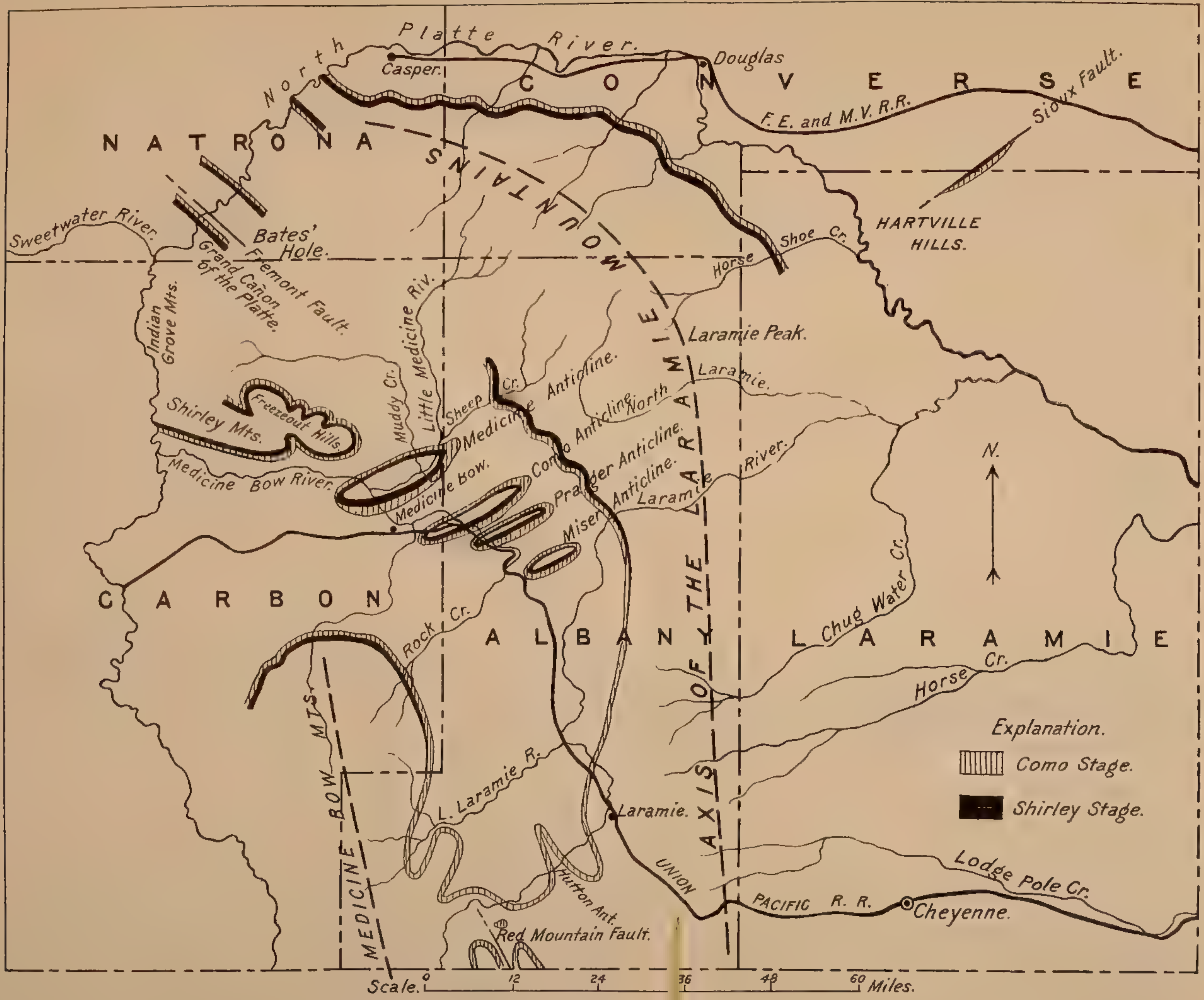
INTRODUCTION

In Wyoming, as in many of the Rocky Mountain states, there has been but very little detailed geological work done, and our present very limited knowledge is largely based on the reports of the early reconnaissance surveys. Large areas remain unknown to science that have not been mapped or approximately described. These are more common than is generally supposed, and often contain several hundred square miles. One of these areas extends from the Union Pacific railroad, in Carbon county, north to the Laramie mountains, and from the North Platte river eastward more than 50 miles, and includes the great dinosaur fields that have recently attracted considerable attention, and also constitutes an important portion of the territory to be considered in this paper.



PRELIMINARY MAP OF THE JURASSIC EXPOSURES IN SOUTHEASTERN WYOMING

In southeastern Wyoming, or that portion of the state lying east of the South Platte river and south of the Fremont, Elkhorn and Missouri Valley railroad, the Jurassic rocks are exposed in numerous places.

EARLY INVESTIGATORS

Doctor Hayden refers to the Jurassic* rocks of the Laramie mountains as follows:

> "Resting above the Red beds is a series of marls and arenaceous marls of light or ashen gray color, with harder layers of limestone or fine sandstone, which were also first discovered around the margin of the Black hills in Dakota in 1857. Since the discovery in the Black hills, Jurassic fossils have been found over a very wide geographical area, and yet I have never seen them so well developed, or the peculiar fossils so abundant, as at the locality where they were first observed. Although I have traced this Jurassic belt by its organic remains over many hundreds of miles, I have been able to discover scarcely a well defined Jurassic fossil south of Deer creek, a point 100 miles north of Fort Laramie and south of lake Como on the Union Pacific railroad."

The Fortieth Parallel Survey † reported Jurassic rocks on the Laramie plains as follows:

> "Jurassic rocks occur from Red Buttes southward to Red lake, usually showing but limited outcrops, and those confined chiefly to the calcareous portions of the series. Upon the summit of the high Triassic plateau southeast of Red Buttes are exposures, about 200 feet thick, of Jurassic rocks, the summit members having been eroded off. Beginning at the top, the beds are as follows: A sandstone body 100 feet thick, white and friable at the top, reddish brown, slightly intercalated with variegated clays and marls in the middle, passing downward into cream colored, marly sandstone; beneath this is 25 feet of bluish gray, cherty limestone, followed by 75 feet of bluish white sandstone, which rests upon the yellowish red, cross-bedded sandstones of the top of the Trias.
>
> "At the dome-like quaquaversal at the northern edge of map I, near the 106th meridian, at Como, the easily recognized Dakota sandstone and conglomerates overlie a series of Jurassic rocks, which are exposed from 175 to 200 feet. Passing downward from the base of the Dakota Cretaceous, the Jurassic rocks consist of first, gray clays and sandy marls, containing a great many gritty particles of angular silicious sand; secondly, creamy marls, with thin, sandy layers; thirdly, bluish drab, cherty limestones; fourthly, fine ash colored marls, with thin beds, varying in thickness, of light colored limestones; fifthly, gray and orange colored marls, with

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* Geological Survey of Wyoming and contiguous territory, 1870, pp. 21, 22, 28. See also Lieutenant G. K. Warren: Preliminary Report of Explorations in Nebraska Territory and Dakota, 1855–'56–'57. B. D. Meek and F. V. Hayden: Paleontology of the upper Missouri; numerous references to type species discovered along the North Platte river, especially near Red Butte.

† Clarence King: Systematic Geology, Fortieth Parallel Survey, 1878, pp. 286–287; also Geological Survey of the Territories, F. V. Hayden, 1867–'69, pp. 82, 89, 113; also Geological Survey of Wyoming and contiguous territory, 1870, p. 131.

coarse, sandy intercalations; sixthly, a reddish yellow sandstone, which is immediately succeeded by a brick red, compact sandstone of the Trias. In the marls, both above and below the limestones, which lie a little above the middle of the series, occur numerous Jurassic forms, among them the following:

"*Pentacrinus asteriscus*, *Belemnites densus*, *Tancredia warreniana*, and *Trigonia quadrangularis*."

Since the days of Hayden and the Fortieth Parallel Survey nothing of geological importance has been published relative to this portion of Wyoming, which is a peculiar combination of plains, tablelands, valleys, canyons, hills, and mountains. Unfortunately, a complete description of the topographical features must be deferred to some future time, and only those referred to that are directly associated with the Jurassic exposures.

Mountain Ranges, Folds, and Faults

The Laramie mountains, the longest range, extend from the Colorado line north to Laramie peak, and thence north and westward to the North Platte river. Westward from the Laramie mountains, across the Laramie plains, are the Medicine Bow mountains, which are the northern extension of the Park range, nearly paralleling the Laramie mountains, and are found as far north as Elk mountain, where the older rocks disappear beneath the more recent. In the western-central part are the Shirley mountains, which are in reality the Seminoe mountains, on the east side of the North Platte river, and north of these the Indian Grove mountains, which are granite peaks scattered along the east side of the North Platte river, as far north as the Sweetwater river. Beside these prominent elevations are the Freezeout hills east of the Shirley mountains and the Hartville hills north of Fort Laramie. There are also several anticlinal folds and some faults that have played an important part in exposing Jurassic bands. South and east of the Freezeout hills are four anticlinal folds extending northeast and southwest or at a right angle to the Freezeout uplift and other orographic movements about the Laramie plains. Singularly enough the forces making these folds operated from the southeast, while those making the mountain ranges came from the west and south. These folds are only a few miles apart and vary from 8 to 20 miles in length. They may hereafter be known by the following names, commencing at the one nearest the Freezeout hills: Medicine,* Como,† Prager,‡ and Miser.§ Southwest of Laramie 20 miles is the Hutton* anticline, which is a spur-like projection from the Laramie mountains, extending northwest. At Alcova, a postoffice on the North Platte river below the mouth of the Sweetwater, is the Fremont† fault, which is very extensive and is the source of the Hot springs at that point. In the northeastern corner of the area is the Sioux‡ fault, where the Jurassic rocks have been elevated until on a level with the Miocene Tertiary. At Red mountain, at the southern end of the Laramie plains, the Red Mountain fault has disturbed the Jurassic.

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* Named from the Medicine Bow river, which is in this vicinity.

† This has been referred to many times as the Como uplift.

‡ Named in honor of Frank Prager, the oldest pioneer in this region.

§ Named from Miser siding, which is located on this fold.

Distribution of Jurassic Rocks

The distribution of the Jurassic rocks conforms very closely to the disturbances just described. They occur in narrow bands flanking the mountain ranges, encircling the anticlinal folds, and as isolated areas along faults. In some instances the Miocene rocks have entirely obscured many miles of the older sedimentaries flanking the ranges. On the eastern slope of the Laramie mountains from the Colorado line as far north as Horseshoe creek the Miocene originally covered nearly all of Mesozoic and Paleozoic strata.

Jurassic rocks are not known within the above limits, but may be found in some of the valleys which have suffered great denudation, as Horse creek and Chugwater creek. Triassic sandstones are exposed in these valleys at the foot of the mountains. From Horseshoe creek the Jurassic bands can be traced along the northern flank of the Laramie mountains to the Platte river to a point 8 or 10 miles west of Casper, and in all probability there are some exposures paralleling this range north of Laramie peak which have been caused by a slight secondary fold. Along the western slope of the Laramie mountains the Jurassic bands extend north and northwest to a point a few miles beyond Sheep creek, where they disappear beneath the Tertiary. Likewise, after following the irregular outline of the eastern and northern slopes of the Medicine Bow mountains, this series disappears several miles southwest of Elk mountain beneath more recent formations. They are likewise buried on the north side of the Shirley mountains, and the exposures near the Fremont and Sioux faults disappear in both directions beneath the Miocene. The remaining exposures are to some extent covered with debris and soil, but are often seen rising in the abrupt bluffs with steep slopes and capped with Dakota sandstone and conglomerate. Within this area there are not less than 450 linear miles of exposure.

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* Named from Hutton lakes, which are in this vicinity.

† Named in honor of Fremont, who first described the hot springs flowing from this fault.

‡ Named after the Sioux nation.

To illustrate the lithological characters of these beds three sections have been selected from widely separated localities.

SIOUX FAULT SECTION

The first one is the Sioux Fault section, which is the farthest east of the eastern Jurassic exposures, with the exception of the Black hills:

CRETACEOUS:

Dakota conglomerate and sandstone.

JURASSIC:

		Feet
1.	Variegated marls and clays shading from yellow to dark maroon, with dinosaurian remains	38½
2.	Calcareous sandstone	2
3.	Bluish and yellowish marls, containing Brontasaurus at top and Morosaurus at base	22½
4.	Drab calcareous sandstone	1½
5.	Light colored clays and marls, with thin bands of sandstone	24
6.	Clays and marls varying from light gray to brown	23½
7.	Hard band of light gray clay	4½
8.	Drab and greenish clays	22½
9.	Drab sandstone	2
10.	Yellow, greenish, and light brown marls shading into maroon in the upper portion	38½
11.	Gray sandstones	3
12.	Bluish gray clay	4
13.	Bluish and drab clays interstratified with yellowish bands	38½
	Total thickness of Freshwater beds	226
14.	Variegated clays and marls with bands of sandstone	43½
15.	Yellowish sandstone	8½
16.	Dark shale beds with remains of Baptanodon, Belemnites, Ostrea, Tancredia, Comtonectes, and a few Septeria	38½
17.	Yellowish sandstone	2½
18.	Gray sandstone	5½
19.	Yellowish sandstone alternating with thin clay bands	6½
20.	Thin bedded gray sandstones with a few bands of clay	5½
	Total thickness of Marine series exposed	118

Triassic not exposed.

FREEZEOUT HILLS SECTION

CRETACEOUS:

1. Dakota conglomerate.

JURASSIC:

		Feet
2.	Drab marls and clays with a few thin bands of light colored sandstone containing remains of Dinosaurs	55

	Feet
3. Hard clay and sand containing freshwater mollusks and crocodiles.	1½
4. Drab marls and clays with a few bands of calcareous sandstone with remains of Alosaurus, Diplodicus, Brontosaurus, Morosaurus, and Stegosaurus, Ceratodus and Turtles	24½
5. Drab marls and clays with thin beds of soft sandstone	46
6. Yellowish soft sandstone with cycads and petrified wood	10
7. Brown sandstone, cross-bedded	2
8. Drab shales, clays, and marls	70
9. Greenish sandstone	4
Total Freshwater beds	211
10. Reddish and brown shales and clays	49
11. Dark fossiliferous limestone with Camptonectes and Ostrea	2
12. Greenish shales with dark bands of clay and sandstone, with clay containing concretions of limestone, rich in fossils. Fossils present: Belemnites, Pentacrinus, Astarta, Grammatodon, Ostrea, Pseudomonotis, Pleuromia, Pinna, Lima, Megalneusaurus, Baptanodon, and Plesiosaurus	50
13. Gray sandstone	4
14. Red and brown shales with concretions and a few fossils.	44
15. White sandstone with upper band containing fossils	30
Total Marine beds	179

TRIASSIC: Red sandstone.

RED MOUNTAIN SECTION

CRETACEOUS:

Dakota removed but present in most instances.

JURASSIC:

	Feet
1. Drab marls and clay with two thin bands of limestone and one of chert and chalcedony with Dinosaur remains	35
2. Drab limestone	2
3. Variegated marls with Dinosaur remains	38
4. Gray limestone	1
5. Drab marls and clays	39
6. Gray sandstone	6
7. Drab marls and clays	69
8. Gray sandstone and some conglomerate	20
9. Drab and red marls and clays	25
Total, all freshwater deposits	235

Sandstones are usually calcareous. Thin-section rests on the Triassic red sandstone.

CORRELATION OF THE SECTIONS

The upper portions of the Sioux fault and Freezeout sections bear a marked resemblance to the entire Red Mountain section. So far as known, these are freshwater beds containing an abundance of dinosaur life, a few fishes, turtles, and crocodiles, together with the cycads and petrified wood. This series has long been called the Freshwater Jurassic and, by the late Professor Marsh, Atlantosaurus beds. Various opinions have been held as to the exact position these should be referred to, but it has usually been conceded that they are Jurassic. Professor Scott a few years ago conditionally referred them to the Lower Cretaceous, but in a recent letter to me considered them Jurassic.

The lower half of the Sioux fault and Freezeout sections is also very similar, and had the fauna of the two localities been carefully collected the similarity would be more marked. These beds are marine and contain a fauna of both vertebrate and invertebrate, many species of which are new to science and have not been described. They have been called the marine Jurassic and also designated as the Baptanodon beds;* a better term would have been Belemnites beds. The Marine series were not found at Red mountain.

GROUPING OF THE JURASSIC

ITS DIVISIONS

In grouping the Eastern Rocky Mountain Jurassic there are but two distinct divisions to consider, although there are local and unimportant developments between the two stages. In the Freezeout hills there are great lenses of white sandstone that sometimes attain a thickness of 25 or more feet.

COMO STAGE AND ITS FOSSILS

The freshwater beds have already been named the Como stage by Professor Scott.† This stage may be defined as follows: A formation that is beneath the sandstone and conglomerates of the Dakota stage and is composed of marls, clays, and sandstones, the marls and clays varying in color from drab to maroon with occasional yellowish bands. These are separated by thin bands of light colored sandstone and limestone and occasionally there are bands of calcareous sandstone containing chert and chalcedony. Usually the Como stage is about 200 feet in thickness, sometimes attaining 250 feet and decreasing to 150 feet. Associated with the marl beds are the following fossils:

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*See Marsh: Am. Jour. Sci., vol. xvii, 1879, p. 86. Sauranodon being preoccupied was replaced with Baptanodon.

†See W. B. Scott: Introduction to Geology, p. 477, footnote.

Vertebrates

FISHES

Ceratodus robustus, Knight.
Ceratodus americanus, Knight.
Ceratodus guntheri, Marsh.

REPTILES

The following reptiles are most common, though many more have been reported :

Dinosaurs[*]

Brontosaurus excelsus, Marsh.
Morosaurus grandis, Marsh.
Allosaurus fragilis, Marsh.
Coelurus fragilis, Marsh.
Stegosaurus ungulatus, Marsh.
Camptosaurus dispar, Marsh.
Laosaurus gracilis, Marsh.
Diplodocus longus, Marsh.

Marsh's names only have been used in reference to Dinosaurs, but without question the work of Cope deserves a place and will receive attention as soon as the synonymy has been worked out.

Crocodiles

Crocodiles have been found in numerous places, but few of the remains have been studied.

Goniopholis felix, Marsh.

Turtles

Compremys plicatulus, Cope.
Glytops ornatus,

The genus Trionyx is known, and possibly there are several species.

MAMMALS

Allodon laticeps, Marsh.
Allodon fortis, Marsh.
Dryolestes arcuatus, Marsh.
Dryolestes priscus, Marsh.
Dryolestes obtusus, Marsh.
Dryolestes gracilis, Marsh.
Dryolestes vorax, Marsh.
Menacodon rarus, Marsh.
Ctenacodon nauns, Marsh.
Ctenacodon serratus, Marsh.
Ctenacodon potens, Marsh.
Docodon striatus, Marsh.
Laodon venustus, Marsh.
Stylacodon gracilis, Marsh.
Stylacodon validus, Marsh.
Enneodon crassus, Marsh.
Enneodon affinis, Marsh.
Priacodon ferox, Marsh.
Tinodon bellus, Marsh.
Tinodon robustus, Marsh.
Tinodon lepidus, Marsh.
Diplocynodon victor, Marsh.
Paurodon valens, Marsh.
Triconodon bisulcus, Marsh.
Asthenodon segnis, Marsh.

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[*] Some 25 or more species of Dinosaurs have been reported from the Como stage. Many of these have been established upon a single bone or at most a few, and beyond question when the animals are better known the number will be greatly reduced. This will not only affect species, but genera, and beyond question higher divisions. Only those are referred to that appear to have an unquestionable standing.

INVERTEBRATES

Only a few species of freshwater invertebrates are known. These belong to the genera Unio, Planorbis, and allied forms. Many of these fossils are new to science and will shortly be described by Doctor E. H. Barbour.

PLANTS

CYCADS*

A new genus represented by 20 new species, none of which have yet been published. There are also numerous species of petrified wood.

EXTENT OF COMO STAGE

The Como stage is quite extensive, its northern limit being in Montana and its southern at least in southern Colorado. These beds are known in the Black hills and as far west as the 109th meridian.

SHIRLEY STAGE AND ITS FOSSILS

The marine division may hereafter be known as the Shirley† stage, which is composed of bands of shale, limestone, sandstone, and clay. The limestones are usually shaly. The limestone beds are quite thin, but usually fossiliferous. The clays and shales usually contain large concretions which contain both vertebrate and invertebrate fossils. Septaria are common. The invertebrate as well as vertebrate faunas are only partly known. This has been largely due to the fact that the richest fossil localities are where the concretions are well developed, and until recently not many of these were known.

INVERTEBRATES

Some of the important invertebrate species‡ that mark this stage are

Lingula brevirostris, M. & H.
Ostrea engelmanni, Meek.
Lima sp.
Lima n. sp.
Comptonectes extenuata, M. & H.
Tancredia cf. *extensa*, White.
Tancredia warrenana, M. & H.
Pholodomya kingi, Meek.
Thracia weedi, Stanton.
Pleuromya sp.

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* It is only recently that cycads have been found in unquestionable Jurassic rocks in America, and this first discovery was made in the Freezeout hills during the summer of 1898 by a party of the University of Wyoming. The collection made was not large, but has been placed in Doctor Ward's hands, of the United States Geological Survey, for study, and he has already reported that he has found in the collection one new genus and twenty new species of cycads.

† Name taken from the Shirley mountains, on the south side of which this formation is very well developed.

‡ I am indebted to Doctor T. W. Stanton, of the United States Geological Survey, for the identification of the greater portion of this list.

Comptonectes sp.
Comptonectes bellistriata, Meek.
Pseudomonotis curta, Hall.
Pseudomonotis orbiculata, Whitfield.
Modiola sp.
Pinna sp.
Grammatodon inornatus, M. & H.
Astarta packardi, White.
Astarta, sp.
Tancredia cf. *inornata*, (M. & H.) Whitfield.
Pleuromya subcompressa, Meek.
Goniomya montanaensis, Meek.
Belemnites densus, M. & H.
Cardioceras cardiformis, M. & H.
Cardioceras cardiformis, var. *distans*, Whitfield.
Cardioceras sp.
Cardioceras ? sp.
Pentacrinus asteriscus,[*] M. & H.
Gryphæa nebrascensis, M. & H.
Dentalium subquadratus, Meek.

VERTEBRATES

But few vertebrates have been found in this stage, and Baptanodon is the most common. The following species of Wyoming reptiles have been reported :

Baptanodon discus, Marsh.
Baptanodon natens, Marsh.
Megalneusaurus rex, Knight.

In the collection of the University of Wyoming there are two new Plesiosaurs which have not been described and an Inchthyosaur which resembles the genus Ichthysaurus of Europe, it being very much larger than Baptanodon. The Plesiosaurs are small and appear to resemble Liassic forms of Europe.

The Jurassic fishes recently discovered in the Black hills by N. H. Darton and described by Doctor C. R. Eastman in all probability belong to the Shirley stage. These species are

Pholidophorus americanus, Eastman.
Amiopsis dartoni, Eastman.

Doctor Eastman,[†] in describing *P. americanus*, says " that it is not far removed from *P. bechei*, Agassiz, from the lower Lias."

EXTENT OF SHIRLEY STAGE

The Shirley stage varies in thickness from a few to nearly 200 feet, and thickens in its north and western extension from southeastern Wyoming. The limits of this stage are not as well known as the Como, but extends from the Miser anticlinal north and eastward to the Black hills and to the westward. It is possible that the Ellis stage of the Yellowstone park may be in part the Shirley. Since the Shirley stage is not known in southern Wyoming and northern Colorado, it is evident that the Triassic had been elevated above the sea during the deposition of this series, and that it was again submerged at the commencement of the Como. The unconformabilities formed by these changes are apparent, but have not been detected.

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[*] Only last summer I discovered the head of *Pentacrinus asteriscus*. This species was described from its column by Professor Meek in 1858. Until the present discovery nothing of the head has been known. Professor Clark, of Johns Hopkins, will shortly figure and describe this, the only American Jurassic Pentacrinus.

[†] Bull. Geol. Soc. Am., vol. 10, p. 405.

THE JURA AND JURA-TRIAS

Early writers * on Rocky Mountain geology called these stages Jurassic without hesitation. In more recent years a fauna was discovered in western Wyoming and eastern Idaho which was supposed to be a mixture of Jurassic and Triassic types. In consequence the term Jura-Trias † was introduced, and since that time it has been applied alike to the rocks of the eastern Rocky mountains and to those farther west. There seems to be no reasonable ground for continuing the name Jura-Trias for the eastern Rocky mountains, for the Jurassic rocks are easily distinguished from the " Red beds," which may be either Permian or Triassic. Lithologically they favor the Triassic and should be so considered unless a fauna or flora should prove them otherwise.

SUGGESTIONS AS TO CORRELATION

The correlation of these stages with those of European Jurassic can not be satisfactorily accomplished until more is known of the American fauna. Professor Hyatt ‡ has already suggested that the Rocky Mountain Jurassic corresponds to the Upper and Middle Jurassic of England, in which case the Como would equal the Oxfordian, and the Shirley the Oolites. There can be no mistake in assigning the Como stage to the Upper Jurassic, but it seems quite possible that it is more closely allied to the Purbeckian than to the Oxfordian.

The Shirley stage presents a series of complications which renders its correlation with the foreign Jurassic an impossibility in the present condition of our knowledge, and it seems quite possible that there is no corresponding member in Europe. The invertebrate fauna is not extensive, and there is a great scarcity of Cephalopods, which are the leading horizon indicators of Europe. To review the invertebrate fauna, it seems quite probable that this stage also should be assigned to the Upper Jurassic. On the other hand, the vertebrate evidence is so conflicting that one is at a loss to suggest a corresponding stage. For instance, two plesiosaurs and some fishes have been discovered which have Liassic

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* See early writers, Hayden's reports of the United States Geological Survey of the Territories from 1868 to 1876, inclusive; also earlier papers by Meek & Hayden. The Forteith Parallel Survey and all literature relating to this formation in the Rocky mountains prior to 1877.

† See United States Geological Survey of the Territories of Idaho and Montana, 1877, Hayden, pp. 359, 556, 559–561, 621–623, 625, 626, 628.

‡ See Bull. Geol. Soc. Am., vol. 3, 1892, pp. 409, 410.

characters. The American Ichthyosaurs, so far as known, are closely allied to the European Opthalmosaurus,* which is Middle Jurassic, and the great Magalneusaurus † is closely related to the English Pliosaurus, which is Upper Jurassic. In view of these facts, no further suggestion can be offered at this time. In this, as in other stages, harmony should prevail in the evidence offered, and until the great difference can be removed it must suffice to call the Shirley stage Jurassic, but remembering that the bulk of evidence offered at the present time would not place it higher than Middle Jurassic.

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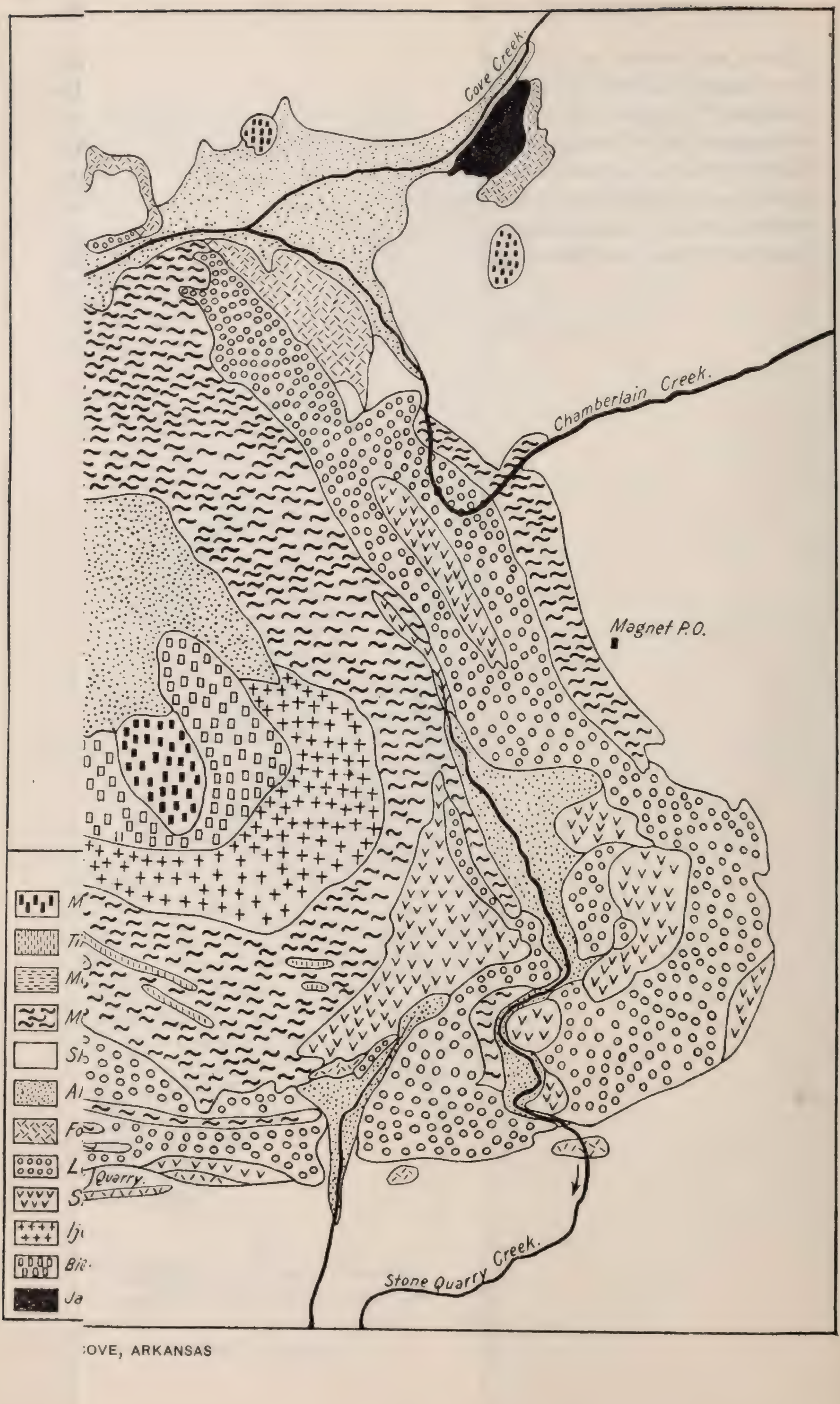
* A. S. Woodward: "Vertebrate Paleontology," p. 183.

† Am. Jour. Sci., vol. v, pp. 378–380.



COVE, ARKANSAS

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IGNEOUS COMPLEX OF MAGNET COVE, ARKANSAS

BY HENRY S. WASHINGTON

(Presented before the Society December 30, 1899)

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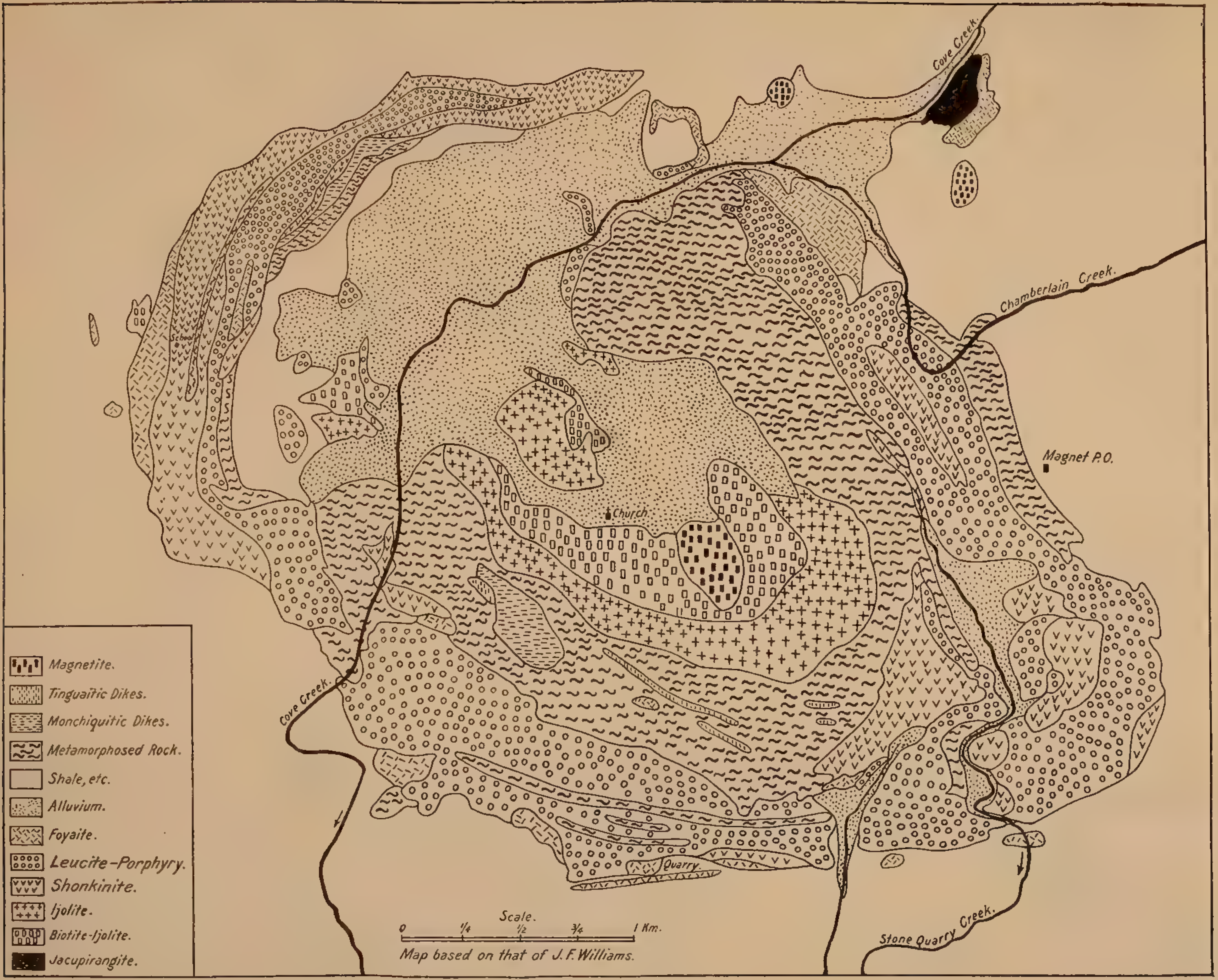

GEOLOGICAL MAP OF MAGNET COVE, ARKANSAS

PART I.—GEOLOGIC STRUCTURE OF THE COMPLEX

INTRODUCTORY

The igneous rocks of Arkansas, especially those of Magnet Cove, have become classical through the careful and detailed work of the late J. F. Williams, whose volume[*] is, of course, well known to all petrographers. Study of his work, and especially of the map which he gives, led me to think that the structure of the mass and the relationships of the various rocks were not such as were briefly indicated by him, as will be shown later, but that the complex forms an excellent, though peculiar, example of a highly differentiated mass of magma, probably a laccolith, the rocks of which form a series of very interesting types.

It must be remembered that at the time Williams wrote his report the notion of laccoliths had not become widely accepted, especially in Germany, where he had studied. Furthermore, at this time none of the most striking and now well known examples of differentiated laccolithic masses had been described. Indeed, the idea of the differentiation of magmas was only beginning to take definite shape, the classical paper of Rosenbusch[†] dating from 1889, the work of Brögger[‡] on the Christiania region appearing in 1890, and that of Iddings[§] in 1892. It is therefore not surprising, and does not detract from the high standard of Williams' work, that such topics are omitted from his discussion, and that he barely refers[||] to the differentiation of the magmas.

In the spring of 1899 I had the opportunity of spending a few days at Magnet Cove. While the results did not come up to my expectations in all respects, yet my observations confirmed me in my idea, and they, with the material collected, enabled me to examine the subject on my own account, the results of which study I now purpose to give.

The descriptions of the rocks by Williams are so detailed and complete that scarcely anything can be added to our knowledge of them in this direction. The analyses he gives are numerous, covering most of the types, and are satisfactory in most cases; so that here also but few additions are needed. It is therefore chiefly with the structure of the mass and the relations of the various rocks that we shall concern ourselves, since on these two important points Williams expressed his views very briefly, and it is in these respects only that I find reason to differ with him.

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[*] J. F. Williams: "The Igneous Rocks of Arkansas." Ann. Rept. Geol. Survey of Arkansas for 1890. Little Rock, 1891.

[†] Rosenbusch, in Tsch. Min. Pet. Mitth., vol. xi, 1889, p. 144.

[‡] W. C. Brögger, in Zeit. Kryst., vol. xvi, 1890.

[§] J. P. Iddings, in Bull. Phil. Soc. Wash., vol. xii, 1892, p. 90.

[||] Williams, op. cit., p. 3.

A rough geological map, based on that of Williams, is given, as reference to it is necessary for proper understanding of the main questions. It only gives the main features and larger areas, with some of the dikes, while the contour lines have been omitted, so that for details occasionally mentioned the reader must consult the original.

GEOLOGIC POSITION

The igneous rocks of Magnet Cove are situated in an area of much folded Carboniferous shales and sandstones south of the Lower Silurian area, which extends from Hot Springs to Little Rock, and on the southeastern border of the Ouachita uplift. It is surrounded at some distance on the north, east and south, and partly on the west, by novaculite ridges forming part of the peculiar zigzags described by Griswold.*

The comparatively late age of these rocks was first determined by Branner † and confirmed by Griswold ‡ and Williams.§ The last says: "All the igneous rocks are younger than the surrounding Paleozoic rocks and have forced their way into them. They were formed after the folding and bending and after some of the erosion of the Paleozoic rock had been accomplished, probably during late Cretaceous times." Branner has lately || expressed the opinion that the Arkansas syenite intrusions are of Tertiary age. It is only necessary to say that my observations fully confirm the view that the intrusions were subsequent to the disturbance of the surrounding Paleozoic rocks, and also Williams' statement ¶ that all the igneous rocks are undoubtedly intrusive in character, and that no extrusive flows or ash-beds were observed.

STRUCTURE OF THE MASS.

Obstacles to observation.—Unfortunately, the conditions are far from ideal for the study of the structure and of the relationships of the igneous rocks to each other and to the surrounding sedimentaries. The greater part of the area, especially the annular " Ridge " and the igneous patches elsewhere, is densely wooded and covered deeply with leaves and soil, while in the " Cove " basin, most of which is under cultivation, the accumulation of detritus and the products of decomposition of the

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* L. S. Griswold: Novaculites of Arkansas. Ann. Rept. Geol. Survey of Arkansas for 1890, vol. iii, chap. xv.

† J. C. Branner, in Proc. Amer. Ass. Adv. Sci., vol. xxxvii, 1888, p. 188.

‡ Griswold: Op. cit., p. 321.

§ Williams: Op. cit., p. 342.

|| Am. Jour. Sci., vol. iv, 1897, p. 365.

¶ Williams: Op. cit., p. 343.

basic rocks prevent any very satisfactory examination. Railroad cuts and quarries (except the Diamond Jo) are not to be found, and the streams have not eroded in such a way as to help us materially.

The difficulty of exact determination thus arising is frequently remarked on by Williams,* who, on this account, does not claim great accuracy in the details of his map, especially in the dikes, the positions of many of which could only be inferred by boulder trains, though the main areas are quite certain.

Williams' views.—The explanation which Williams offers of the relationships of the various rocks may be given in his own words,† a few unimportant phrases being omitted:

> "The igneous rocks of Magnet Cove are divided into three genetically distinct groups, whose structure and mode of occurrence show that they were formed during three distinct periods of igneous activity. The oldest of these consist of the basic, eleolitic, abyssal rocks which constitute a large part of the interior Cove basin. The large masses of these rocks are holocrystalline granitic in their structure and were cooled slowly and under pressure. During the next period the rock in and about the Cove, which had been disturbed and heated by the intrusion of the masses of abyssal rocks, cooled and cracks opened in all directions. These cracks are filled with monchiquitic rocks. The third and last period of activity is that in which the eleolitic and leucitic rocks of the "Cove ring" were formed, and during which the numerous tinguaitic dikes of all varieties were intruded. The rocks of this period are all of an intrusive character, a fact which is shown by their structure and mode of occurrence. These youngest rocks cut both the abyssal rocks and the dikes of monchiquite, and are therefore younger than either of these groups."

The facts observed in the field and in the laboratory do not seem to me to bear out this idea of three genetically distinct groups of rocks and three distinct periods of intrusion. On the contrary, they point rather to the view that the rocks are all genetically connected, and that the mass as a whole is probably a laccolith, and was, at any rate, formed by a single intrusion of magma, which differentiation has split up into two main groups of central, basic, ijolitic rocks, and peripheral, less basic, syenites, the monchiquitic and tinguaitic dikes being both contemporaneous and subsequent injections of these differentiates into the cracked cover and cooled igneous mass and surrounding rocks.

Form of the area.—The igneous area has an approximately circular or rather broadly elliptical shape, the two axes measuring about 5 and 3 kilometers, the direction of the major axis being about west-northwest by east-southeast. The central portion or "Cove basin" is low—from

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* Williams: Op. cit., pp. 173-201 passim.

† Williams: Op. cit., p. 342.

330 to 420 meters above the sea. This part is largely covered with alluvial deposits. Surrounding this and generally concentric with the outline of the area is the "Ridge," which reaches an elevation of 650 meters on the west, 590 on the south, and 570 on the east. On the north it is lower, being cut through by Cove creek. This ridge slopes down, occasionally steeply, to the surrounding shales. The cove is drained by Cove creek, which, cutting through at the north, flows through the western part of the basin, cuts the ridge again at the southwest, in a narrow valley, and goes off to the south. A small stream, known as Stone Quarry creek, flows south in the outer part of the igneous area.

Outside of the main igneous area occurrences of igneous rock of any size are rare. There is a small patch of "basic eleolite syenite," which lies just northeast of the main mass. A large number of dikes, mostly small, are found in the surrounding shales and novaculites, as well as in the main area. These have in general, but by no means always, a more or less east-and-west trend. The rocks immediately about the mass are shales and sandstones, while beyond these are the novaculite ridges.

Relation to surrounding shales.—These shales are very much folded, the disturbance having taken place prior to the igneous intrusion. The conditions therefore are not favorable for the observation of one of the most characteristic features of a laccolith, namely, the upbending of the surrounding strata on all sides by the magma. Notwithstanding this, evidences of such upturning have been observed at several places, both by Williams and myself. The best of these is the contact shown at Diamond Jo quarry, described and figured by Williams.* This, by the way, is still preserved. The shales here have been bent upward, dipping about 55 degrees to the south, and are highly metamorphosed at the contact.

Other places in which similar relations have been observed by Williams or myself are near the mouth of Neusch's gully, another point a little farther up Cove creek, near J. M. Henry number 5, and near D. R. Rutherford number 2. At none of these, however, is the bending up of the shales as well shown as at Diamond Jo quarry, though at each the dip of the upturned strata is in a general way away from the igneous complex—that is, quaquaversal.

The surrounding shales are highly metamorphosed at or near the contact where this is visible, as has been described by Williams. Similarly the sandstone near W. W. Brown, at the extreme west end of the area, is reddened, baked, and much shattered.

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* Williams: Op. cit., p. 298, pl. 18.

The "Ridge."—Apart from the surrounding shales and sandstones, there is seen within the igneous area itself a horseshoe of what Williams calls hornstone, or metamorphosed rock. This is either dark or almost white, from rather coarse grained to aphanitic, often showing, apparently, traces of stratification, and in most cases is evidently a highly metamorphosed shale. This view is substantiated by microscopic study of the specimens of these and of the shales at the contact in Diamond Jo quarry which I collected. An important feature of the occurrence of these hornstones is that they occupy the highest parts of the southern ridge, extending also around to the northeast over the succession of hills north of the basin. They are also found in thin strips on the northwest inside the syenite, and bands of them are seen crossing the leucite-syenite south of the main ridge. In every case these hornstones overlie, as far as can be ascertained, the contiguous igneous rocks, which have in places broken up through them. I could find no place along the "Ridge" where this relation was absolutely proved, but a pretty thorough examination, together with consideration of the topographic relations and the presence of dikes, left no doubt in my mind that the "hornstone" overlies the igneous rocks.

Arrangement of the igneous rocks.—A most important and suggestive feature is the arrangement of the various igneous rocks. Although in places hidden by alluvium and forest, yet the exposures are quite sufficient to show the main features with clearness and certainty. The four main types of abyssal rock are seen to occur in zones concentric about a center and with the borders of the area. At the center, in the Cove, we find the coarse grained, very basic "eleolite-mica-syenite (Cove type)" with a central patch of soil full of masses of magnetite and decomposed biotite. Williams suggests that this patch of "magnetite" is derived from the decomposition of a rock more basic than the light Cove type and approximating to the dark Cove type found just outside the main area to the northeast. This seems very probable, and in the discussion I have assumed it to be true.

Surrounding this on the east, south, and west is a zone of somewhat less basic and rather finer grained ijolite (eleolite-garnet-syenite, Ridge type).* This is not seen on the north, except for a small patch, but we can scarcely doubt that it encircles the other here also, though covered by alluvium. It is also met with beneath the hill of *kalksinter* in the basin, together with syenite of the "Cove type," though the relations between the two are not quite clear.

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*There is a serious error in the legend of Williams' map. The designations "Magnetite" and "Eleolite-garnet-syenite (Ridge type)" opposite the second and third color squares should be interchanged. An area in the northeast which Williams colors as ijolite I found to be a foyaite, and have so given it in my map. The mistake was undoubtedly the printer's.

Surrounding the ijolite zone, and lying above it, is a somewhat irregular zone of metamorphosed rock (hornstone) which occupies the summit of the ridge, as already mentioned. Surrounding this hornstone zone, all round the Cove, except at the west where it lies inside this, is a broad zone of leucite-porphyry which is fine grained and porphyritic. This is apt to be mingled in places in a confusing way with tinguaites and the nepheline-syenites, especially the "fine grained variety." The tinguaites, however, are quite subordinate in amount, and scarcely interfere with the general arrangement.

Along the edges of the igneous area at various points are found small patches and large strips of nepheline-syenite. This is either a rather coarse grained foyaite[*] (Diamond Jo type) or a fine grained shonkinitic syenite. The small patches at the extreme periphery are of foyaite, and a strip of this is also seen at the border of the western side, while patches are noticed in the surrounding shales. The shonkinitic syenite forms a large strip on the west, with the Diamond Jo type beyond (outside) it; is also met with along Cove creek and apparently above the leucite-syenite at the northeast, and also as a rather large patch in the southeastern part. In Diamond Jo quarry the foyaite shows a distinct system of joint planes dipping about 80 degrees southwest and splitting it into thick plates. It is true that, as Williams says, the relationship of these types to the leucite-porphyry is most confusing, and that the two tend to commingle, but the evidence is clear that the foyaite (Diamond Jo type) occupies the extreme peripheral position along a good part of the border, while the relations of the "fine grained" (shonkinitic) syenite to the leucite-porphyry are uncertain, though the former lies apparently outside or above the latter.

Transition forms.—In general it is impossible to say whether these various types are sharply separated from each other or whether they grade into each other through transition phases. This is especially true of the first three, the contacts between them being quite hidden, though the probabilities are that the divisions are not sharp. The two syenites certainly, as Williams says,[†] "pass into one another without showing any line of separation whatever."

He also remarks on a sort of flow structure seen in the foyaite, arguing therefrom that the leucite-porphyry cooled first. Judging from the way in which the two commingle and from the confused manner in which masses of tinguaite are mixed with them, it seems highly probable that there was considerable motion in the outer portion, due probably to convection currents. This was after differentiation and probably before crystallization had set in to any great extent, since, while the two grade into one another, the transition zone seems to be narrow, and leucite crystals are not found in the foyaite, nor large orthoclase crystals in the leucite-porphyry.

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[*] I use foyaite throughout this paper as a general term for nepheline-syenite, with trachytoid structure. Cf. Brögger, Zeit. Kryst., vol. xvi, 1890, p. 39.

[*] Williams: Op. cit., p. 277.

RESUMÉ OF EVIDENCE

All the foregoing facts are in favor of the view that the area is probably a section of a laccolith, and, at any rate, that the main rock types are differentiates *in situ* of one mass of magma. For convenience they may be briefly recapitulated:

1. The broadly elliptical shape of the area, surrounded by shales and sandstones.
2. The quaquaversal upturning and the metamorphism of the contiguous shales at many places along the border.
3. The existence of a zone of what is apparently highly metamorphosed shale along the highest parts of the ridge and elsewhere on the outer slope, representing the remains of the original cover.
4. A platy parting approximately parallel to the walls, which has been developed in places in the foyaite.
5. The serial arrangement of the various igneous rocks from the center outward and concentric with the general border of the igneous area.
6. The, on the whole, regular change in structure and size of grain from the center to the periphery.

ALTERNATIVE HYPOTHESES

Williams' reasons for calling the syenites "dike rocks" are,* as far as I can understand, the evidence of flow in their structure, as already noted, and the porphyritic structure of the "leucite-syenites" and a tendency to trachytoid structure in the foyaites. These characters are, however, what we might expect to find in the rocks at the borders of such a mass, since convection currents would be more likely to develop here, and the border magma would naturally cool more quickly, and hence give rise to such structural peculiarities. It must also be remembered that "the more basic a magma the more granular and the coarser its degree of crystallization."†

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* Williams: Op. cit., p. 277.

† Pirsson: 18th Ann. Rept. U. S. Geol. Survey, part iii, 1898, p. 575; cf. Iddings: 12th Ann. Rept. U. S. Geol. Survey, 1892, pp. 626 and 645.

Other objections are that the syenites greatly surpass the ijolites in volume, and that their concentric arrangement about the center is, to the best of my knowledge, quite unparalleled in dikes elsewhere; also, according to Williams' view, we should expect to find the basic syenites beneath the "hornstone" zone, but, on the contrary, it is always syenite, either leucitic or nephelinic, which crops out through this, as is seen on Williams' map.

The few instances mentioned by Williams* to prove that the syenites are later than the ijolites and the monchiquitic dikes are of small moment and not conclusive, since they are just as easily accounted for as last injections of still fluid syenite magma in the cracked complex.

Apart from Williams' view of two distinct periods of intrusion (besides that of the monchiquitic dikes), which we have seen to be untenable, the only alternative to differentiation of an originally homogeneous mass which occurs to me is the "osmotic hypothesis" of Johnston-Lavis.† This supposes the variation in composition of a rock mass to be due to interaction of the magma with the conduit rock. The surrounding rocks here, as far as we know them, are either sandstones or the more abundant shales. The composition of a similar shale from Little Rock ‡ is given here:

$$SiO_2 = 56.30,\ Al_2O_3 = 23.39,\ Fe_2O_3 = 9.29,\ MgO = 1.49,\ CaO = 0.36,$$
$$Na_2O = 2.76, K_2O = 1.36, H_2O = 5.16, FeS_2 = 0.26;\ \text{sum} = 100.37.$$

It will be evident later that these shales could not furnish enough silica and alkalies to "acidify" (feldspathize) the first and basic part of the magma in a way corresponding with the explanation given by Johnston-Lavis in the case of Square Butte.§ Indeed, any such explanation based on successive upwellings of material seems to be quite out of the question, and, inasmuch as such shales, or else sandstones or novaculites, form all the country rock of this part of Arkansas, Johnston-Lavis' hypothesis must be regarded as untenable here.

Since erosion and stream action have not cut deeply into the complex, we have no knowledge of its lower part. We do not know whether there is a true floor, as in the typical laccolith, or whether the mass of igneous rock extends downward for an indefinite distance as a stock. We can only be certain from the contacts at the borders and from the presence of the ridge of metamorphosed rock that the igneous complex which is visible is the uppermost portion of a mass. For this reason any section would be largely hypothetical, so none is attempted here.

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* Williams: Op. cit., pp. 174, 188, 342.

† Johnston-Lavis: Nat. Sci., vol. iv, 1894, p. 134.

‡ Williams: Op. cit., p. 263.

§ Johnston-Lavis: Report Brit. A. A. S., 1896.

The presence of the "Ridge" of hornstone forbids the assumption of a form of laccolith such as those figured by Cross and Pirsson, of considerable regularity, great comparative depth, and with zones of approximately uniform thickness throughout.

This difficulty, however, disappears to a large extent if we assume that the mass has a depth very small as compared with the breadth—*i. e.*, of the shape of a thick disk. In a mass of magma of such a form the zones produced by differentiation would be thicker near the edges, while at the top and bottom they would be much thinner.* Such a thinning out of the zones above would, with the presence of the overlying soil, serve to explain the absence of any of the syenitic rocks inside the hornstone ridge. This, then, may be regarded provisionally as the form and structure of the mass, but any verification of this hypothesis is for the present impossible.

But the question whether the mass is a true laccolith, as it seems to be, or a stock or other form of intrusive mass, is, after all, of secondary importance. This would not, so far as we know, materially affect the processes of differentiation. The main point which I have tried to bring out, and on which special emphasis is laid, is that the various abyssal igneous rocks are integral parts of one mass, and that they are of contemporaneous origin and not due to successive intrusions. This view is indicated with great probability, if not conclusively, by the facts already given; but belief in it will be much strengthened by the petrographical and chemical details to be mentioned presently.

Part II.—Petrology of Magnet Cove

DESCRIPTION OF THE MAIN IGNEOUS TYPES

For the present we shall deal only with the main abyssal types, leaving the rocks which form the small dikes, constituting but a minute fraction of the mass, for a later page.

In Table I are given analyses of the six main rock types, four of them being given by Williams and the other two made by myself.

The first of these (I) is of the foyaite of Diamond Jo quarry. It is very light gray, generally granitic in structure, but occasionally becoming trachytoid. It is composed mainly of orthoclase in large tabular crystals, considerable nepheline, some cancrinite (apparently primary, at least in part), and ægirine and ægirine-augite. Biotite, sodalite, titanite, and magnetite are rare accessories, but amphibole and apatite are not present.

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*Cf. Pirsson: Twentieth Ann. Rept. U. S. Geol. Survey, 1900, pt. iii, p. 564.

Table I.—Analyses of the Six main Rock Types from the Border to the Center

	I.	II.	III.	IV.	V.	VI.
SiO_2	53.38	50.96	49.70	41.75	38.93	36.51
Al_2O_3	20.22	19 67	18.85	17.09	15.41	8.22
Fe_2O_3	1.56	7.76	3.39	6.35	5.10	8.29
FeO	1.99	....	4.32	3.41	4.24	3.31
MgO	0.29	0.36	2.32	4.71	5.57	8.19
CaO	3.29	4.38	7.91	14.57	16.49	18.85
Na_2O	7.89	7.96	5.33	6.17	5.27	2.10
K_2O	6.21	6.77	4.95	3.98	1.78	1.08
H_2O (ignit.)	3.43	1.38	1.09	0.62	5.20	1.40
H_2O (110°)			0.25	0.28		
TiO_2	....	0.52	1.33	0.58	1.62	3.11
X	....	....	....	....		2.10
MnO	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.
P_2O_5	....	....	....	1.09	0.35	....
Cl	....	0.25	....	....	0.02	0.03
FeS_2	1.77	....	....	....	0.89	6.03
	100.03	100.01	99.44	100.60	100.87[*]	99.22

I. Foyaite, Diamond Jo quarry; Brackett and Smith, analysts. Williams: Op. cit., p. 238.

II. Leucite-porphyry, near Diamond Jo quarry; Noyes, analyst. Williams: Op. cit., p. 276.

III. Shonkinite, below school, west border; Washington, analyst.

IV. Ijolite, below Doctor Thornton's; Washington, analyst.

V. Biotite-ijolite, near Baptist church; J. F. Williams, analyst. Williams: Op. cit., p. 226.

VI. Jacupirangite, northeast of Magnet Cove; J. F. Williams, analyst. Williams: Op. cit., p. 227.

II is of the leucite-porphyry[†] near the Diamond Jo quarry. This is composed of leucite, or rather pseudo-leucite, phenocrysts, often of large size, lying in a dark, fine grained, holocrystalline groundmass of nephelite, sharply automorphic brown garnets, diopside, and ægirine, with very little orthoclase, titanite, magnetite, apatite, and probably sodalite.

III is of the rock which Williams calls "fine grained nepheline-syenite," from below the school-house near the western border. It is a rather fine grained, mottled white and black rock, composed of orthoclase with nepheline, diopside with borders of ægirine, some greenish hornblende, rather abundant beautifully sharp crystals of titanite, and accessory apatite and magnetite. It will be seen that in chemical composition this rock closely approaches the leucite-porphyry, though a little lower in SiO_2 and alkalies, and higher in MgO and CaO. It differs mineralogically in that orthoclase replaces leucite, and hornblende and titanite replace garnet. It is thus another example to be added to the rapidly growing list of magmas which are closely similar in chemical composition, but which form on solidification diverse mineral aggregates.

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[*] Williams gives 100.57.

[†] Williams and Rosenbusch call this syenite. Its structure is by no means granitic; it may be called leucite-porphyry provisionally.

In the hand specimen the rock shows considerable resemblance to the shonkinites of Pirsson.* They also resemble these under the microscope, though in the shonkinites augite is more abundant, biotite replaces hornblende, and there is practically no nepheline. Corresponding to these differences the shonkinites are more basic, MgO and CaO being much higher and Al_2O_3 and alkalies lower. At the same time the two evidently belong to the same type of magma, so that for the sake of convenience this fine grained syenite may be called shonkinite. It is closely similar chemically to the essexites and theralites, though it differs mineralogically, as it contains neither plagioclase nor olivine. It may be noted that Rosenbusch † speaks of essexite as occurring in Arkansas, without specifying the locality. He possibly refers to this rock.

IV is of a fairly typical specimen of Williams' "Ridge-type of eleolite-garnet-syenite." It is dark and rather coarse to rather fine grained, with a granitic structure. It is composed of fresh nepheline in large amount, with much pale green or yellow diopside, and xenomorphic brown garnet, which is younger than the pyroxene. Apatite is present in rather large crystals, while magnetite varies, being rare in some specimens and abundant in others. Hornblende, olivine, orthoclase, and plagioclase are absent.

This rock corresponds very closely both chemically and mineralogically with the ijolite described by Ramsay and Berghell ‡ from Iiwaara, in Finland, and is therefore to be recognized as another occurrence of this very interesting type.

V is of Williams' "eleolite-mica-syenite (light Cove type)," a coarse grained rock of granitic structure, the color being in general pinkish or yellowish, mottled with black. It is composed of nepheline, brown garnet (both melanite and schorlomite), some biotite and diopside, a little orthoclase, and titanite, magnetite, and apatite. There is neither hornblende, olivine, nor plagioclase present. This rock may be called biotite-ijolite.

Judging from the specimens which I collected, these two rocks, IV and V, do not differ materially, though the latter does contain some biotite and is coarser grained. The prominence given to the biotite by Williams is apparently due chiefly to its abundance in the altered form of protovermiculite in the soil of the "Cove," especially at the "lodestone bed." Judging from the large size of the protovermiculite plates and of the masses of magnetite and schorlomite found here, it seems very probable that they are derived from a much coarser grained and more basic rock, more nearly allied to the jacupirangites. A deep boring at this point would be of the greatest interest.

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* Weed and Pirsson: Bull. Geol. Soc. Amer., vol. vi, 1895, p. 389.

† Rosenbusch: Elem. Gesteinslehre., p. 173.

‡ Ramsay and Berghell: Geol. För. Förh. Stock., vol. xii, 1891, p. 300.

VI[*] is of Williams' "eleolite-mica-syenite (dark Cove type)" from the small area northeast of the Cove. It is a dark brown and very coarse grained rock, composed for the most part of a violet brown augite (evidently titaniferous), some brown biotite (often in poikilitic crystals inclosing augite and magnetite), with magnetite and some interstitial nepheline. Hornblende, olivine, and feldspars are wanting.

This rock varies much in the relative amounts of augite and magnetite, the latter sometimes being present in large quantity. It is evidently closely allied to the pyroxenites, and seems to be identical, or almost so (except that it is not schistose), with the jacupirangites of Brazil described by Derby,[†] so that it may be called by that name. From the minerals found at the central "lodestone bed" it is probable (and is here assumed) that this analysis represents fairly the composition of the central patch of the Magnet Cove complex.

GENERAL MINERALOGICAL FEATURES

It is evident that mineralogically these types are all closely related and grade into one another. Nepheline is present in all—abundantly in the intermediate types, but more sparingly in the most acid and most basic extremes. Melanite, or a brown garnet, is also very common. It may be mentioned incidentally that from the low TiO_2 found in III it is probable that the abundant garnet in this rock is not a schorlomite or iiwaarite rich in TiO_2, but a more normal andradite. This is confirmed by an analysis of garnet from Magnet Cove by Stromeyer,[‡] which only showed about 3 per cent of TiO_2. The more basic iolites are, however, richer in titaniferous melanite or schorlomite.

The prevailing ferromagnesian mineral is pyroxene, which varies from ægirine and ægirine-augite in the syenites, through diopside, to a titaniferous augite in the most basic rock. Hornblende seems to be quite wanting except in the basic, syenitic shonkinite, and biotite is rare except in the most basic rocks. Magnetite increases regularly as SiO_2 falls, becoming an important constituent in the jacupirangites. Titanite and apatite are quite common, being abundant in certain types. Orthoclase is the only feldspar observed, the more acid rocks, of course, being the richest in it, though it is found even in some of the basic ones. The total absence of the anorthite molecule is remarkable, in view of the abundance of CaO. It is to be noted that olivine is entirely absent from all these rocks, being found in the region only in a few dikes of monchiquite, which will be mentioned later.

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[*] The analysis is rather unsatisfactory, inasmuch as there is an abnormally large amount of CaO, giving an excess above that needed to form augite. A new analysis of this type is highly desirable, but any probable change in the results would not affect the general discussion.

[†] Derby: Am. Jour. Sci., vol. xli, 1891, p. 314.

[‡] Quoted in Hintze. Mineralogie, vol. ii, no. lxiv, p. 91.

GENERAL CHEMICAL FEATURES

Chemically also these rocks are all related to one another and are all evidently derived from the same magma. They are all essentially soda rocks, this alkali being abundant in all of them and to a large extent giving them their characteristic features. In fact this region is another instance of the well known tendency of soda-rich intermediate magmas to undergo differentiation. Na_2O is constantly greater than K_2O in ratios varying from 1.75 to 4.47, and this ratio increases on the whole with the basicity, as has been found to be the case elsewhere.

In the next place, they are rich in CaO, the ijolities extremely so, and even the nephelinic syenites carry far more CaO than such rocks from other regions. The rocks are, on the whole, poor in MgO. This, together with the richness in CaO, accounts for the abundance of melanite, since there was not sufficient MgO to combine with all the CaO to form pyroxene.

Iron oxides offer no especial features of interest, though they are not as abundant in the ijolites as we might expect to find them. No definite relationship between their ratios and SiO_2 can be made out, but, as has been observed elsewhere in soda-rich rocks,* the ratio of $FeO : Fe_2O_3$ is constantly low. Alumina is decidedly high for rocks as basic as the ijolites, and SiO_2 is, on the whole, low; in fact, the character of the magma, as a whole, is decidedly basic as well as rich in soda and lime.

CHEMICAL RELATIONS

The chemical relations of the various rocks are well seen in the accompanying diagram, in which total iron oxides are reckoned as FeO. The agreement of Al_2O_3, Na_2O, and K_2O with each other, on the one hand, and of CaO, MgO, and FeO, on the other, as well as the antagonism of these two groups of oxides, are clearly shown. As silica increases, the former rise regularly with it, while the latter fall as regularly. This behavior, however, is well known and calls for no comment.

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*Washington: Jour. of Geology, vol. vii, 1899, p. 467.

SERIAL CHARACTER

The diagram makes more evident another feature, already shown by the analyses, namely, the serial character of the six types. They all vary continuously in one direction, with scarcely a break or abnormality of any kind. Indeed, these six rocks are an excellent example of a rock series as defined by Brögger.* So well marked is the series, and so regular is the variation from the center outward, that our belief in the integral and contemporaneous character of the various rock types of the mass is changed almost into a certainty. It is scarcely possible that such a regular variation would be found in any complex made up of successive intrusions, still less that they should have been intruded so nicely in their proper order. Some kind of differentiation of the igneous magma as a whole is the only possible explanation, and it seems to me that this complex of Magnet Cove, with its beautifully developed zonal structure, its series of interesting types, and the way in which the component rocks fit into their places in the series, both chemically and mineralogically, forms one of the most striking instances in favor of the differentiation hypothesis which has yet been found.

It will be seen in the diagram that there is a rather large gap in the center between $SiO_2 = 41.75$ and 49.70—that is, between the ijolites and the syenites. As the six analyses represent all the main types observed, it seems hardly possible that another exists which fits into this gap. It suggests rather that the main course of differentiation has split the magma into the ijolites and the syenites, and that their varieties are due to a secondary differentiation of these main differentiates. The ijolitic and syenitic rocks are then to be regarded as the melanocratic and leucocratic complementary divisions of the series.

THE DIKES

General trend of the dikes.—Before discussing the problem of differentiation and comparing the rocks of Magnet Cove with those of other regions, a few words may be devoted to the dikes, in the attempt to see where they fit into the general scheme. As a preliminary it may be stated that the majority of them show a general east-and-west trend—that is, between northwest and southwest. This is approximately par-

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* Brögger: Eruptivgesteine des Kristianigebietes, vol. i, 1894, p. 169.

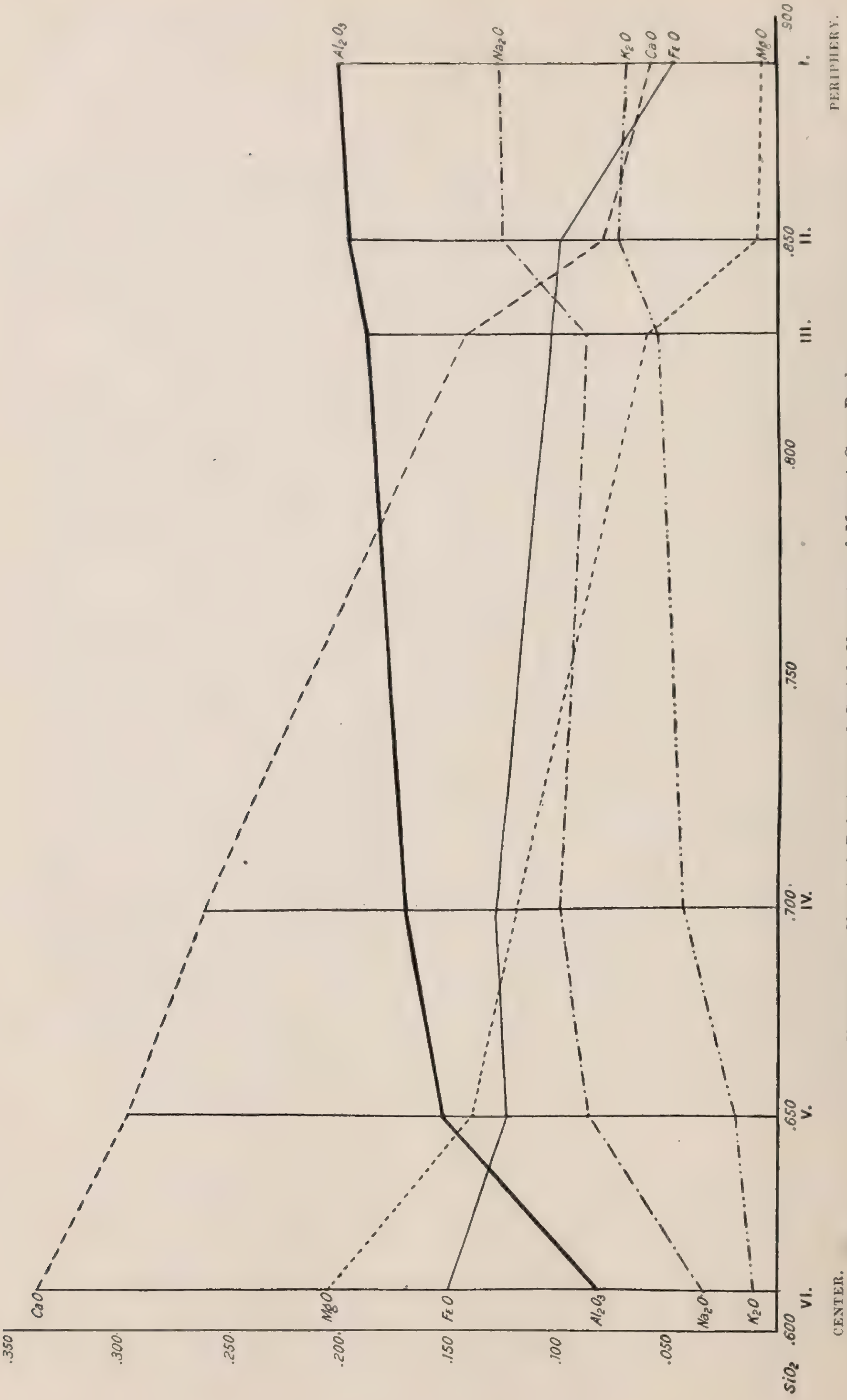

FIGURE 1.—*Chemical Relations and Serial Character of Magnet Cove Rocks.*

allel to the general line of folding in this region. There are some exceptions, but that is the usual course. This is to be expected, since cracks or lines of weakness would naturally develop parallel to the anticlinal axes, and would hence be the lines along which the dike magmas would be injected. It will also have been noticed that the major axis of the igneous area is also approximately parallel to this.

The dike rocks.—The dikes are composed of "nepheline-tinguaites" and leucite-tinguaites, basic nepheline-porphyries, fourchites, and monchiquites. They have been so thoroughly described by Williams that the reader is referred to his work for details. I would merely remark that the rock which he calls "nepheline-tinguaite" comes more properly under the head of tinguaite-porphyry, as used by Pirsson,* orthoclase phenocrysts being abundant, though the groundmass is quite black and aphanitic. Some of his leucite-tinguaites also contain no leucite, but are very typical tinguaites proper. The nepheline-porphyries and the larger masses of monchiquitic rocks, as well as the largest dikes of tinguaite-porphyry, are found in the hornstone area along the Ridge. Leucite-tinguaite seems to occur only in close connection with the leucite-porphyry as irregular schlieren-like masses rather than in dike form, especially toward the borders. They may best be regarded as merely facies of this or of the foyaite or shonkinitic syenite.

Chemical composition.—The analyses here given illustrate the chemical characters of these dikes. It will be seen that the tinguaites resemble the three syenites closely. The tinguaite-porphyry especially is almost identical with the foyaite, and one of the leucite-tinguaites also resembles it, except that Fe_2O_3 and K_2O are considerably higher. The "nepheline-felsite" seems to represent an intermediate type not found among the abyssal rocks. The nepheline-porphyry, fourchite, and monchiquite, on the other hand, resemble rather the ijolite. This is especially true of the nepheline-porphyry, as was noticed by Williams.†

The fourchites and monchiquites differ considerably from this. Their alkalies are very much lower and iron oxides higher (except as compared with the jacupirangite), though the ratio, $Na_2O : K_2O$, still remains high. In the biotite-rich ouachitites, again, MgO is very high, and, while total alkalies remain about the same, yet K_2O is much higher than Na_2O.

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* Pirsson: 18th Ann. Rept. Geol. Survey U. S., part iii, 1898, p. 567.

† Williams: Op. cit., p. 261.

Table II.—Analyses of the Dike Rocks

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	53.76	52.91	51.35	44.50	43.50	42.03	36.40
Al_2O_3	23.21	19.49	20.21	22.96	18.06	13.60	12.94
Fe_2O_3	1.27	4.78	4.90	6.84	7.52	7.55	8.27
FeO	3.18	2.05	....		7.64	6.65	4.59
MgO	0.23	0.29	1.53	1.65	3.47	6.41	11.44
CaO	2.94	2.47	5.75	8.65	13.39	14.15	14.46
Na_2O	6.97	7.13	4.43	6.70	2.00	1.83	0.97
K_2O	7.01	7.88	6.68	4.83	1.30	0.97	3.01
H_2O (ignit.)	1.71	1.19	....	2.06	1.22	1.08	2.36
TiO_2	None.	None.	0.80	1.40	2.10	3.70	0.42
MnO	None.	0.44	....	....	....	Trace.	....
SrO	0.04	0.09	....	....	....	....	....
P_2O_5	Trace.	Trace.	0.28	....	....	0.57	1.04
SO_3	....	....	0.04	....	....	0.08	....
FeS_2	....	0.52*	4.01	....	....	0.56	....
Cl	0.02	0.53	0.06†	....	....	0.05†	....
CO_2	....	None.	....	....	....	....	3.94
	100.34	100.25	100.04	99.59	100.20	99.23	99.84

I. Tinguaite-porphyry, The Ridge; Williams, analyst. Williams: Op. cit., p. 266.

II. Leucite-tinguaite, Neusch's gully; Williams, analyst. Williams: Op. cit., p. 287, with X = 0.48.

III. "Nepheline-felsite," north of Doctor Thornton's; Noyes, analyst. Williams: Op. cit., p. 263.

IV. Nepheline-porphyry, Doctor Thornton's; Noyes, analyst. Williams: Op. cit., p. 261.

V. Amphibole-monchiquite, Dike 159; Noyes, analyst. Williams: Op. cit., p. 295.

VI. Fourchite, Fourche mountain, Arkansas; Noyes, analyst. Williams: Op. cit., p. 108.

VII. Ouachitite, Dike 18, near Hot Springs; Eakins, analyst. Williams: Op. cit., p. 399. Bull. 148, U. S. Geological Survey, 1897, p. 96.

On comparing the molecular ratios of these dike rocks with those of the main types shown in the diagram it is found that the analyses of the tinguaites and basic nepheline-porphyry fall in very satisfactorily with the lines as there given; but the analyses of the fourchites, monchiquites, and ouachitites do not fit in at all well, great discrepancies occurring all along the lines, rendering them irregular, with sharp and abrupt zigzags.

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* S. † $NaCl$.

It is to be inferred from this, I think, that the tinguaites and nepheline-porphyry are aschistic[*] dikes—that is, undifferentiated injections of the still fluid differential zones into the surrounding rock—while the fourchites, etcetera, are diaschistic dikes—that is, products of a still further differentiation of these zones.

THE ZONAL ARRANGEMENT

Peculiarity of order of rocks.—Turning to the question of the order of arrangement, it will be seen that a very peculiar feature of this complex is that this differs from nearly all other laccolithic and other masses of igneous rock in the order in which the component rocks occur. In some laccoliths, such as those of Colorado, Utah, and Arizona, described by Gilbert[†] and Cross,[‡] and those of the Judith,[§] Castle,[||] and Little Belt[¶] mountains in Montana, described by Weed and Pirsson, the igneous mass is of practically uniform composition throughout. The rocks of all these, it is to be noted, are granite and syenite porphyries and porphyrites, all decidedly acid rocks and not very highly alkaline in character.

In others, as Predazzo,[**] Brandberget,[††] Garabal hill,[‡‡] Carrock fell,[§§] and Square butte,[||||] Yogo peak,[¶¶] and Bearpaw peak,[***] in Montana, composed either of rather basic or rather alkaline rocks, where the magma has differentiated after intrusion, the border zone is basic and the interior more acid. The same relations are observed in many composite dikes. These cases have led us to believe that the oxides of iron, magnesium, and calcium tend to diffuse toward the cooling surface, while the alumina, alkalies, and silica tend to remain in the hotter (central) part.

At Magnet Cove we find exactly the contrary. The iron oxides, magnesia, and lime are most abundant at the center, and silica, alumina, and alkalies at the borders. The same oxides are differentiated, but their direction of motion, if we may so express it, is reversed.

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[*] Brögger: Eruptgesteine des Kristianiagebietes, vol. i, 1894, p. 125; cf. Washington: Jour. of Geol., vol. vii, 1899, p. 472.

[†] Gilbert: Geology of Henry Mountains, Washington, 1877.

[‡] Cross: Fourteenth Ann. Rept. U. S. Geological Survey, 1895, p. 157.

[§] Weed and Pirsson: Eighteenth Ann. Rept. U. S. Geological Survey, 1898, pt. iii, p. 437.

[||] Weed and Pirsson: Bull. no. 139, U. S. Geological Survey, 1896.

[¶] Weed and Pirsson: Twentieth Ann. Rept. U. S. Geol. Survey, 1900, pt. iii, p. 562.

[**] Brögger: Eruptivgesteine Krist. gebictes, vol. ii, 1895, p. 66.

[††] Brögger, in Quar. Jour. Geol. Soc., vol. l, 1894, p. 31.

[‡‡] Dakyns and Teall, in Quar. Jour. Geol. Soc., vol. xlviii, 1892, p. 104.

[§§] Harker, in Quar. Jour. Geol. Soc., vol. l, 1894, p. 311, and vol. li, 1895, p. 125.

[||||] Weed and Pirsson, in Bull. Geol. Soc. Am., vol. 6, 1895, p. 389.

[¶¶] Weed and Pirsson, in Am. Jour. Sci., vol. l, 1895, p. 467.

[***] Weed and Pirsson, in Am. Jour. Sci., vol. i, 1896, p. 351.

Other instances.—Although this is contrary to the general rule, yet it is by no means an isolated exception. Brögger[*] furnishes an example, with five analyses, in the laccolithic mass of Ramnäs. Here the center is a medium grained akerite, with $SiO_2 = 58.48$, $CaO = 5.02$, and alkalies = 8.58. This gradually becomes finer grained and more acid as the border is approached, till at the contact at Gislerud the rock is a fine grained quartz-porphyry, with $SiO_2 = 71.49$, $CaO = 0.30$, and alkalies = 10.18. The ratio of $Na_2O : K_2O$ also varies continuously, as in Essex county, Massachusetts, Magnet Cove, and elsewhere.

The diorite stock of the Castle mountains,[†] Montana, may also be mentioned. This is basic at the center, growing less so toward the periphery, where it becomes a very acid quartz-porphyrite.

Another instance is the laccolith of Umptek, Kola, in Finland, described by Ramsay and Hackmann.[‡] This is composed mainly of a peculiar foyaite which has been called chibinite,[§] showing a trachytoid structure, abundant ægirine, arfvedsonite, eudialyte, and other rare minerals, and which is very high in Na_2O.[||] The mass is cut by sheets of finer grained chibinite, theralite, and ijolite, suggesting the idea that they are possibly intrusions of the still fluid basic interior through the already cooled outer mass of chibinite. Lastly and most important, there occurs at the borders of the mass a more acid, nepheline-poor to nepheline-free syenite,[¶] which Ramsay calls umptekite and which is allied to the pulaskite of Fourche mountain, Arkansas. This umptekite, it may be noted, is classed by Ramsay[**] under the *endomorphic* modifications of the main chibinite.

At this center, then, we apparently have a state of affairs closely resembling those of Magnet Cove, both as regards the general chemical characters of the rocks, their occurrence as a laccolith or originally homogeneous mass of magma, and their order of arrangement.

CAUSE OF DIFFERENTIATION

General discussion of causes.—The exceptional character of these occurrences would seem to imply that some, at least, of the principles usually invoked to explain differentiation can not apply here. I say "seem" since it must not be forgotten that it is possible, indeed probable, that several processes may be involved, either simultaneously or separately, in so complicated a matter as the differentiation of a mass of magma. Our notions of the relations of solvent and solute, and of solutions in general, especially as applied to rock magmas and the conditions in which they exist, are at present so vague that we must move with great caution. The matter is complicated by the fact that in such large masses purely physical, as well as physico-chemical and chemical, forces (such as gravity and convection currents), almost certainly come into play. This being the case, it would perhaps be wiser to defer all discussion for the present, but I can not refrain from suggesting an explanation which has certain elements of probability.

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[*] Brögger: Zeit. Kryst., vol. xvi, 1890, p. 45.

[†] Weed and Pirsson: Bull. no. 139, U. S. Geological Survey, 1896, pp. 134 and 140.

[‡] Ramsay and Hackmann: Fennia, vol. 11, no. 2, Helsingfors, 1894.

[§] Brögger: Erupt. gest. d. Krist. geb. iii, 1898, p. 29.

[||] See analyses later on page 412.

[¶] Ramsay and Hackmann: Op. cit., pp. 204 and 214, and figs. 13 and 14, p. 75.

[**] Ramsay and Hackmann: Op. cit., p. 197.

A liquid solution, such as a rock magma may be supposed to be, is a mixture of two or more bodies, one of which is said to act as a solvent for the others—that is, the solutes. The difference between the two is more apparent than real, since in many cases their functions can be interchanged. But the general idea underlying the use of the term solvent is that it is that constituent which is present in excess.* Often either constituent may act as the solvent, and in many such cases it is found that as the solution is cooled socalled eutectic mixtures tend to form.†

Leaving aside the consideration of these, if a more or less dilute solution (that is, one in which the solvent is largely in excess) is cooled sufficiently, or frozen, as it is called, the solvent crystallizes first, the mixture tending to become eutectic. Thus, if we partially freeze an aqueous solution of salt the ice formed is quite pure and the brine more concentrated.

This idea has been applied to the crystallization of magmas by Lagorio,‡ who also suggests § that the general solvent has the composition $(K,Na)_2O.2SiO_2$, basing this conclusion on the results of many analyses. While the exact stoichiometrical character of the solvent in general may be doubted, and while many cases may be cited where such a solvent is out of the question,|| yet in the alkaline rocks, especially those of the foyaitic series, it seems probable that the part of the magma which plays the rôle of the solvent is composed of silica, alumina, and alkalies. Possibly these exist in stoichiometrical ratios, but more probably not.

We would seem to have, then, in this a good explanation of the facts at Magnet Cove, Umptek, and Ramnäs. Just as in a highly cooled vessel of salt water the ice crystallizes at the sides, bottom, and top, leaving a core of more concentrated liquid at the center, so here the solvent may have frozen out, collecting at the borders of the cavity in a more or less

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* Cf. Nernst. Theoretical Chemistry, 1895, p. 414.

† For a résumé of this subject compare Teall. British Petrography, 1888, p. 396.

‡ Lagorio: Tsch. Min. Pet. Mitth., vol. viii, 1887, p. 513.

§ Lagorio: Op. cit., p. 508.

|| On these points see the remarks of Zirkel (Lehrb. Pet., vol. i, 1893, p. 767) and Iddings (Bull. Phil. Soc. Wash., vol. xii, 1892, p. 156).

pure condition, as foyaite, and gradually becoming more basic (richer in the solute) as the freezing process crept toward the center.

Assuming that a certain portion of the magma acts as solvent and another as solute, as it seems we must, such a process is a natural one. It has been advocated by Becker in his paper on Fractional Crystallization,* but in a somewhat different form. According to him the "process depends essentially upon convection currents," and the crystallization proceeds from the least to the most fusible constituents.

On these two points I cannot agree with him. While convection currents would undoubtedly be set up to some extent, and have been apparently in the outer syenitic zones at Magnet Cove, yet they do not seem to me to be essential to the process. It would go on by a simple crystallization of the solvent, thus collecting along the rough borders in accordance with the well known tendency of crystallizing bodies to grow about sharp nuclei, the solute molecules being mechanically pushed aside toward the center.†

That it is not the least fusible substance which crystallizes first is shown by the general truth of Rosenbusch's law of the order of crystallization and the numerous dikes and laccoliths with basic and more fusible borders and acid centers. This is not a question of relative fusibility, but of solvent and solute, degree of dilution and relative solubility.

Different types of laccoliths.—While the conditions are complex, and several possible processes may be involved, yet there is reason for thinking that the composition of the magma as a whole has most to do with the order of arrangement of the crystallized differentiates. If we examine the three classes of laccoliths already mentioned, it is seen that, while in one (Henry Mountain type) the magma is undifferentiated, in the second (Square Butte type) it is differentiated and with a basic border, and in the third (Magnet Cove type) it is differentiated, but with the border acid; yet the conditions of cooling and solidification could not, as far as we can tell, have been very different in the different cases.

I have already pointed out that the three types seem to be distinguishable by the chemical characters of their respective magmas.

The first type of laccolith is granitic or dacitic—that is, very rich in SiO_2, and with relatively small amounts of all other oxides, either alkalies or lime preponderating among these. It may also be noted that the structure of these is always porphyritic.‡ The second is either monzonitic or dioritic, referring to the general character of the magma as a whole before differentiation into zones, with lower SiO_2, and with oxides of Fe, Mg, and Ca either equal to or preponderating over the alkalies. The third is syenitic or foyaitic (also applied to the general magma), rather low in SiO_2, but with either K_2O or Na_2O or both preponderating over the bivalent oxides. (This applies especially to Na_2O, since few or no examples of essentially potash-rich laccolithic masses are known or have been studied.) These last two are uniformly granitic in structure.* Of course, it is not asserted that this is the invariable rule, nor that these three are the only possible types, but the few cases which have been investigated in sufficient detail seem to bear it out in general, though there are apparent exceptions.

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*G. F. Becker: Am. Jour. Sci., vol. iv, 1897, p. 257.

† Examples of this on a small scale are to be seen about the phenocrysts of certain dike rocks. Cf. Pirsson: Am. Jour. Sci., vol. ii, 1896, p. 191; and Washington: Jour. of Geology, vol. vii, 1899, p. 113.

‡ Cf. Pirsson: Twentieth Ann. Rept. U. S. Geol. Survey, 1900, pt. iii, p. 561.

Assuming that such a distinction between the three classes exists in fact, or is at least generally applicable, it is suggested here that the magmas of the first (Henry Mountain) type either approach in composition a eutectic mixture, analogous to that suggested by Teall,† or else that the rocks represent closely the chemical character of the—or a—magmatic solvent, the solution being so dilute that the solvent crystallized in an approximately pure condition, the small amount of solute either being mechanically caught and crystallized with it, or forced inward and solidifying as a very small basic core, yet to be discovered, at the center of the mass. In the other two types the solvent was either (Square Butte type) rich in iron oxides, magnesia and lime, and the solute alkaline and aluminous, or (Magnet Cove type) the converse, the solvent being composed essentially of silica, alumina, and alkalies, and the solute consisting mainly of bivalent oxides. In a possible fourth type, of gabbro or peridotitic magma, the mass would again be quite uniform, since here (analogously with the Henry Mountain type) the basic solvent is largely in excess.

These four types, it must be mentioned, are only given as examples, and are not to be considered as exhausting the possible types of differentiation. These may be very various, and, of course, dependent on the composition of the magma and the physical conditions of cooling. These four are, however, probably the most common and important, though a possible fifth, that of a gabbro magma, with anorthosite and pyroxenite zones, may be added.

This view, which, it must be confessed, is only a working hypothesis, explains otherwise apparently discordant facts in many cases, though it by no means excludes the possibility of other processes being involved. It is generally believed that the laws governing dilute liquid solutions are quite distinct from those involved in more concentrated ones. It is

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* On this point, as regards volcanic rocks, see Jour. Geol., 1895, vol. iii, p. 62.

† Teall: Brit. Petrog., p. 402.

Table III.—Comparison of

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	60.03	59.70	63.71	54.14	46.63	42.79	45.64	45.28
Al_2O	20.76	18.85	16.59	20.61	15.03	19.89	19.50	27.37
Fe_2O_3	4.01	4.85	2.92	3.28	5.91	4.39	3.47	3.53
FeO	0.75	......	0.66	2.08	5.09	2.33	3.34	0.49
MgO	0.80	0.68	0.90	0.83	3.47	1.87	3.04	0.33
CaO	2.62	1.34	3.11	1.85	11.23	11.76	4.45	1.22
Na_2O	5.96	6.29	8.26	9.87	8.16	9.31	11.57	17.29
K_2O	5.48	5.97	2.79	5.25	1.96	1.67	6.96	3.51
H_2O	0.59	1.88	0.19	0.40	0.35	0.99	0.16	0.40
TiO_2	......	......	0.86	0.95	1.12	1.70	2.44	......
ZrO_2	......	......	......	0.92	......	......	......	......
MnO	Trace.	......	0.20	0.25	Trace.	0.41	0.19	0.19
P_2O_5	0.07	......	......	......	......	1.70	......	......
Cl	......	......	......	0.12	......	......	......	......
	101.07	99.56	100.19	100.55	98.95	98.81	100.76	99.53

I. Pulaskite, Fourche mountain, Arkansas; Brackett, analyst. Williams: Op. cit., p. 70.

II. Nepheline-syenite, Fourche mountain, Arkansas; Noyes, analyst. Williams: Op. cit., p. 81.

III. Umptekite, Umpjavr, Umptek; Petersson, analyst. Ramsay: Fennia, vol. xi, 1894, p. 205.

IV. Nepheline-syenite (main type), Tschasnatschorr, Umptek. Ramsay: Fennia, vol. xi, 1894, p. 132.

V. Ijolite, Kaljok valley, Umptek; Berghell, analyst. Ramsay: Op. cit., p. 185.

VI. Ijolite, Iiwaara, Umptek; Berghell, analyst. Ramsay: Op. cit., p. 185.

VII. Nepheline-porphyry, Wudjavrtschorr, Umptek; Hackmann, analyst. Ramsay: Op. cit., p. 151.

VIII. Urtite, Lujavr Urt, Kola; Sahlbom, analyst. Ramsay: Geol. För. Förh. Stock., vol. xviii, 1896, p. 462.

IX. Pulaskite, Moita, Foia, Portugal; Dittrich, analyst. Koschlau and Hackmann: Tsch. Min. Pet. Mitth., vol. xvi, 1896, p. 225.

X. Foyaite, Picota, Portugal; Jannasch, analyst. Koschlau: Op. cit., p. 218.

Analyses of Foyaitic Rocks

IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.	XVIII.	XIX.
60.42	53.96	49.67	41.80	53.74	51.62	49.46	48.90	45.18	47.8	51.88
19.23	21.78	17.99	14.56	14.02	15.63	23.53	7.85	23.31	20.1	14.13
0.63	0.62	13.06	6.09	10.63	6.06	3.04	11.46	6.11	6.7	6.45
3.19	2.55		6.41	1.71	4.98	1.02	13.32		0.8	0.94
0.67	0.54	3.06	4.66	Trace.	Trace.	0.03	0.38	1.45	1.1	3.44
1.73	1.93	6.63	14.87	1.18	3.45	0.80	1.95	4.62	5.4	10.81
6.99	8.61	6.21	4.25	9.02	10.09	14.71	7.40	11.17	5.5	6.72
6.88	7.02	2.62	1.94	4.77	4.19	4.34	3.23	5.94	7.1	4.57
1.74	2.29	0.86	1.18	3.40	2.12	1.38	1.80	1.14	2.4	0.18
....	1.03	....	4.14	....	....	....	....	....	0.7	0.33
....	....	....	....	2.13	2.14	0.54	1.96	....	....	....
Trace.	0.15	....	....	0.36	0.33	....	1.11	....	0.8	....
....	Trace.	....	0.52	....	....	....	....	....	....	0.96
....	Trace.	....	....	....	....	2.25	0.03	....	....	....
101.48	100.48*	100.10	100.82	100.96	100.61	101.27	99.39	98.92	99.3†	100.41

XI. Essexite, Monchique, Portugal; scholar of Jannasch, analyst. Koschlau: Op. cit., p. 239.

XII. Basic segregation in Foyaite, Monchique; Singhof, analyst. Koschlau: Op. cit., p. 237.

XIII. Lujavrite, Kangerdluarsuk, Greenland; Ussing, analyst. Rosenbusch: Elemente d. Gesteinslehre, 1898, p. 126.

XIV. Lujavrite (trachytoid), Kangerdluarsuk. Rosenbusch: Op. cit., p. 126.

XV. Sodalite-syenite, Kangerdluarsuk; Ussing, analyst. Rosenbusch: Op. cit., p. 126.

XVI. Schlieren in Lujavrite, Kangerdluarsuk; Detlefsen, analyst. Rosenbusch: Op. cit., p. 133.

XVII. Nepheline-porphyry (Sussexite), Beemerville, New Jersey; Kemp, analyst. Kemp: Transactions of the New York Academy of Sciences, vol. xi, 1892, p. 60.

XVIII. Borolanite, lake Borolan, Scotland; Player, analyst. Horne and Teall: Transactions of the Royal Society of Edinburgh, vol. xxxviii, 1893, p. 163.

XIX. Garnet-pyroxene-malignite, Poobah lake, Ontario, Canada; Blasdale, analyst. Lawson: Bulletin of the Department of Geology, University of California, vol. i, p. 356.

* Traces of SrO, Li_2O, and S. † Including 0,8 BaO and 0,4 SO_3.

also true that the ionizing action of different solvents varies much both in degree and kind, dissociation taking place in some and to different extents, while association, or an apparent molecular condensation, takes place in others.

Owing to the lack of data, especially as regards concentrated solutions, the whole subject is in a vague and uncertain condition, and I may be allowed to express the hope that the physical chemists, by the investigation of this phase of the study of solutions, and more especially concentrated ones and fused salt mixtures, may soon put us in a position to attack such problems with greater knowledge and consequently greater hope of their ultimate solution.*

At any rate, it would seem that the application of Soret's principle is by no means as general as has been supposed, and indeed some strong objections † have been recently raised against it. Bäckström's liquation theory ‡ certainly contains elements of probability, but seems rather applicable to particular cases, such as orbicular granites, than to differentiated zonal laccolithic masses or dikes. In such cases as these the substance first crystallized would tend to collect and grow from the rough containing walls, the points of which would serve as nuclei. In the case of one liquid separating from another in which it happens to be insoluble under the existing conditions, we have no evidence, so far as I know, that there would be such a tendency. It seems more likely that the insoluble liquid would separate in the form of drops and schlieren.

COMPARISON WITH OTHER REGIONS

A comparison with the rocks of other regions is of great interest, but so much space has been devoted to the preceding discussions that only one or two special points will be mentioned.

In general, it may be said that the rocks of Magnet Cove offer special analogies with those of Kola, Alnö, Greenland, Portugal, Brazil, and Beemerville, New Jersey. These are all regions of foyaitic rocks low in silica and especially high in soda. The chemical resemblances will best be seen on an examination of the analyses given in Table III, which are only a few out of those available. At Magnet Cove the most acid rock is the nepheline-syenite, with 53 per cent of silica; but the pulaskites of the neighboring igneous area of Fourche mountain may reasonably be supposed to be derived from the same general magma. Rocks corresponding to these are found at several of the regions above mentioned. Similarly, among the more basic rocks we find many which correspond both chemically and mineralogically to those of Magnet Cove. There are also analogies with the borolanite of Teall* and the malignites of Lawson,† though in both of these K_2O is relatively much higher.

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* It is encouraging to note that Professor Bancroft has lately (Jour. Phys. Chem., vol. iii, 1899, p. 605) called attention to the neglect of this very important field of research.

† Bäckström, Jour. Geology, vol. i, 1893, p. 773, and G. F. Becker, Am. Jour. Sci., vol. iii, 1897, p. 21.

‡ Bäckström, op. cit.

DIFFERENTIATION ALONG TWO LINES

A study of the rocks of all these regions indicates that magmas rich in soda tend to differentiate toward the basic end along two lines. Along one there is an accumulation of Na_2O, giving rise to such peculiar types as the urtite of Kola with 17 Na_2O, the sodalite-syenite of Kangerdluarsuk with Na_2O up to 14.7, and the sussexite of Beemerville with Na_2O 11. Along the other line iron oxides and lime ‡ tend to accumulate, giving rise at the basic end to the basic segregations of Serra de Monchique, the jacupirangites of Brazil, and similar rocks of Alnö. At Magnet Cove the first branch seems to be absent, since nothing analogous to the urtites, etcetera, is found there; but, on the other hand, the iron-lime branch is represented by the ijolites and jacupirangites.

SUMMARY

The structure of the complex is briefly described, and from the evidence of form of area, relations to surrounding shales, the presence of an overlying zone of metamorphosed rocks, the arrangement and serial petrographical and chemical characters of the main types, together with other minor points, it is shown that the igneous complex is probably a laccolith, and certainly a unit or integral mass of intruded magma. The component abyssal types are not due to successive injections, as was suggested by J. F. Williams, but are the products of a differentiation *in situ* of the originally homogeneous mass of intruded magma ("laccolithic differentiation" of Brögger).

The main rock types are briefly described, some new analyses being given, and they are shown to form a regularly graded series, ranging from foyaite, through leucite-porphyry, shonkinitic syenite, normal ijolite, and biotite-ijolite, to jacupirangite. This serial and common genetic character is shown both mineralogically and chemically. It is probable that the dikes of tinguaite and nepheline-porphyry are aschistic, while those of the monchiquitic rocks are diaschistic.

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* Horne and Teall: Trans. Roy. Soc. Edinb., vol. xxxviii, 1893, p. 163.

† Lawson: Bull. Dept. Geol. Univ. Cal., vol. i, p. 337.

‡ MgO seems to be associated with K_2O when it is abundant together with either of the two alkalies.

The arrangement of the abyssal rocks is abnormal, and differs radically from most other cases of differentiated masses, in that there is progressive increase in acidity toward the periphery, the analogous case at Umptek, in Kola, being especially mentioned. An explanation of this, based on a process of fractional crystallization or freezing of the magma, which is regarded as a solution, the solvent crystallizing first, is given, and the hypothesis is applied to other cases. It is suggested that all laccoliths and similar masses of magma may be referred to at least four different types, dependent on the chemical composition of the magma as a whole, the differences between which would be satisfactorily accounted for by the hypothesis.

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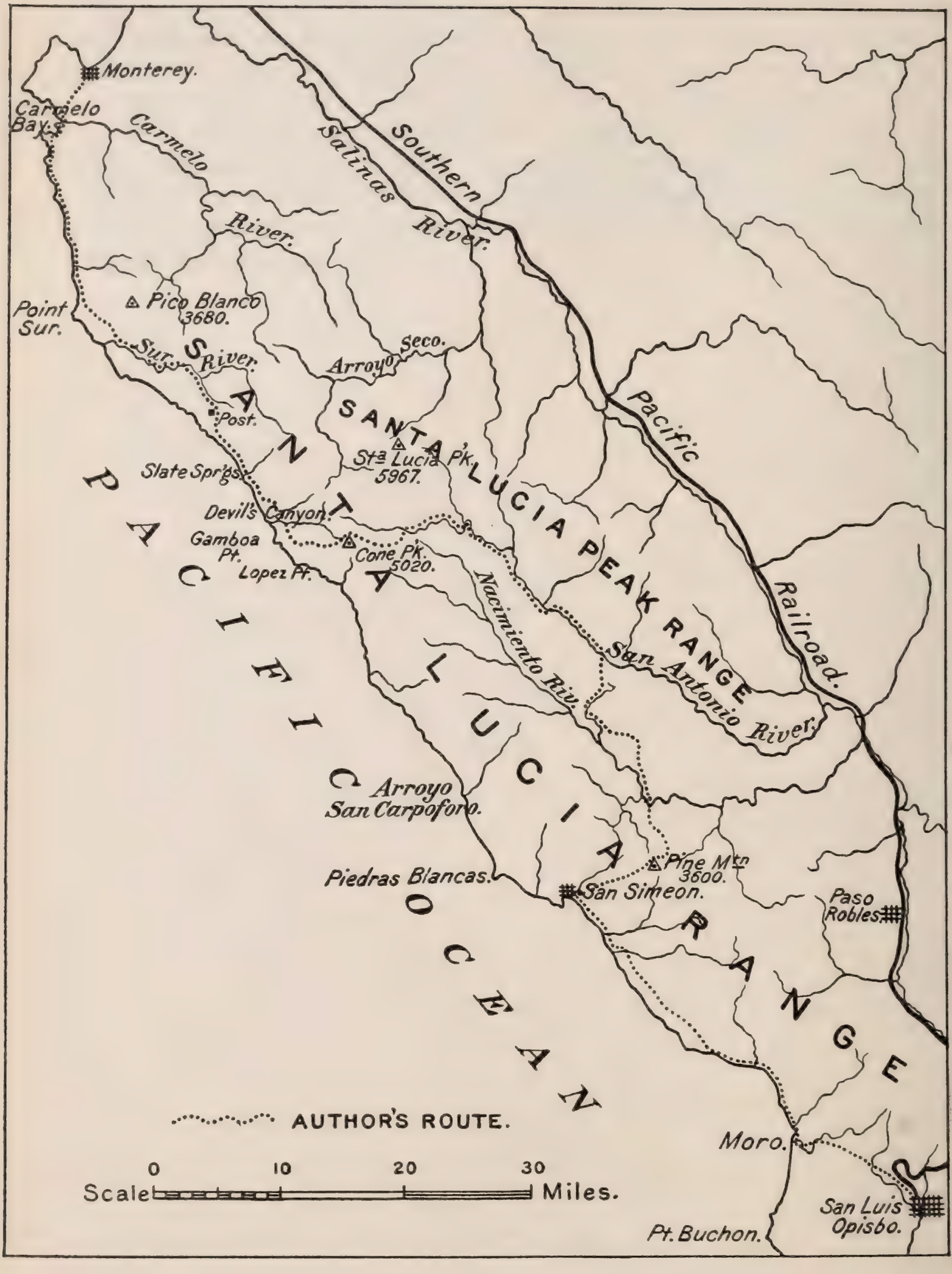

MAP OF SANTA LUCIA RANGE, CALIFORNIA, AND ADJACENT FEATURES

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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SOME COAST MIGRATIONS, SANTA LUCIA RANGE, CALIFORNIA

BY BAILEY WILLIS

(Read before the Society December 27, and before the Cordilleran Section December 29, 1899)

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INTRODUCTORY NOTE

The following article presents observations made during a trip from Monterey to San Luis Obispo along the intervening Coast ranges. I was accompanied by Doctor H. W. Fairbanks, in whose articles many of the facts herein presented have already been published,* and I am indebted to him not only for pointing out the most interesting and significant phenomena of the region, but also for helpful discussion of their interpretation.

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* Stratigraphy of Slate Springs. Amer. Geologist, vol. xviii, 1896.

Professor A. C. Lawson * has described the geology of Carmelo bay just south of Monterey, a district which adjoins on the north that herein referred to and which includes the Santa Lucia granite, the youngest member of the Coast complex hereafter defined. My observations are in general in accord with those made by Lawson at Carmelo bay and by Fairbanks farther south.

The present Scene

Point Sur, a prominence of the California coast, lies 24 miles south of Monterey. From it the coast stretches 57 miles southeast to Piedras Blancas. Along this section extends the westernmost of the Coast ranges, locally known as the Santa Lucia range, which attains elevations of 4,000 to 5,000 feet. The mountains present a bold front to the ocean, precipitous, it is true, only near sealevel at isolated promontories, but generally steep. Ravines gash this front deeply. In general, the aspect of the mountain slope is that of mature topography. In detail, there are variations of form significant of successive episodes of uplift.

Near Slate Springs, 35 miles southeast of point Sur, there are two basal conglomerates—the one, that which is being formed by the waves which now dash against the rocky shore; the other, that which was similarly formed when they broke on a shore of Mesozoic date. The present conglomerate is the beach; the older conglomerate is the base of the Franciscan or Golden Gate series, and rises in cliffs several hundred feet above the beach, the strata dipping 70 to 80 degrees to the southwest. The present conglomerate and the older one both consist largely of pebbles and boulders of a still older complex, which will be called the Coast complex. On the summit and eastern flank of the Santa Lucia range occur strata which are much younger than the Franciscan formation. They constitute a group whose members bring the record down to late Neocene (Pliocene) time.

The sequence thus briefly indicated includes (1) the development of the Coast complex; (2) profound erosion of the Coast complex; (3) deposition of the Franciscan conglomerate, sandstone, and shale; (4) orogenic movements, which resulted in deformation of the Franciscan formation; (5) erosion of the Coast complex and Franciscan rocks, which is partially represented in later sediments; (6) evolution of the present mountain system and coastal front.

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* The Geology of Carmelo bay. University of California, Bull. of the Dept. of Geology, vol. i, pp. 1–50.

The history is a long one, extending from possibly the Paleozoic period to the present, and a very complex one, comprising the phenomena of sedimentation, erosion, metamorphism, orogeny, and perhaps epeirogeny.

Pre-Franciscan History

COAST COMPLEX

The Coast complex consists of crystalline rocks, chiefly metamorphic, including marble, quartzitic schists, mica-schists, gneisses, and granite. The granite is intruded in the others and did not share their experience of profound metamorphism. The marble and schists constitute a sedimentary series. The gneisses may in part or whole have had an igneous origin. The whole has suffered deformation in a deep zone of flow, resulting in structural and mineralogical changes which to a great extent obscure the original characters of the rocks. Fairbanks* has described the series somewhat in detail under the name "basement complex." This term is aptly applied, as the Coast complex is the intricate mosaic at the base of the geologic column in the Coast ranges.

The age of the Coast complex can only be vaguely guessed. It is long pre-Cretaceous; it may probably be Paleozoic. The former statement follows from the age of the succeeding Franciscan rocks, which are either Eo-Cretaceous or Jurassic. The Paleozoic date is an inference on the uncertain grounds of lithologic and structural similarity to the metamorphic complex of the Sierra Nevada.

The oldest rocks of the Coast complex were sediments, either calcareous muds or quartzose sands. The region of their accumulation was therefore marine, but not so remote from land as to escape terrigenous deposits. Land was probably near, since the sediments were buried to that depth which conditions deformation-by-flow and recrystallization, and zones of such great accumulation of sediment are usually shore zones.

PRE-FRANCISCAN EROSION

Pebbles of gneiss and granite from the Coast complex chiefly compose the basal Franciscan conglomerate. These rocks had become surface rocks at the inception of the Franciscan epoch. The elevation of the folded and schistose gneisses from the zone of deformation-by-flow involved orogenic or epeirogenic movements vertically of great amount, and corresponding erosion of the mass. Thus in some pre-Cretaceous epoch a land area succeeded to the sea in this region, and in Franciscan time its shore closely approximated the position of the present shore.

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*Review of our knowledge of the geology of the California Coast ranges. Bull. Geol. Soc. Am., vol. 6, pp. 78–82.

The sediments resulting from the erosion of that land have not been discovered; only the fact of a great hiatus in the record is obvious at the unconformity.

FRANCISCAN HISTORY

FRANCISCAN STRATIGRAPHY

The basal conglomerate of the Franciscan series is a very coarse shore deposit composed of pebbles and boulders up to two or more feet in diameter in a sandy matrix. The materials were derived from the immediately adjacent Coast complex upon which the conglomerate was deposited. The strata exposed in the mountain slope are strikingly like the deposits which constitute the beach at the base of the cliffs, and to realize the aspects of the Franciscan coast the observer needs only to consider those of the present coast. The Franciscan was a bold and rocky shore, against which broke powerful waves (see plates 26 and 27).

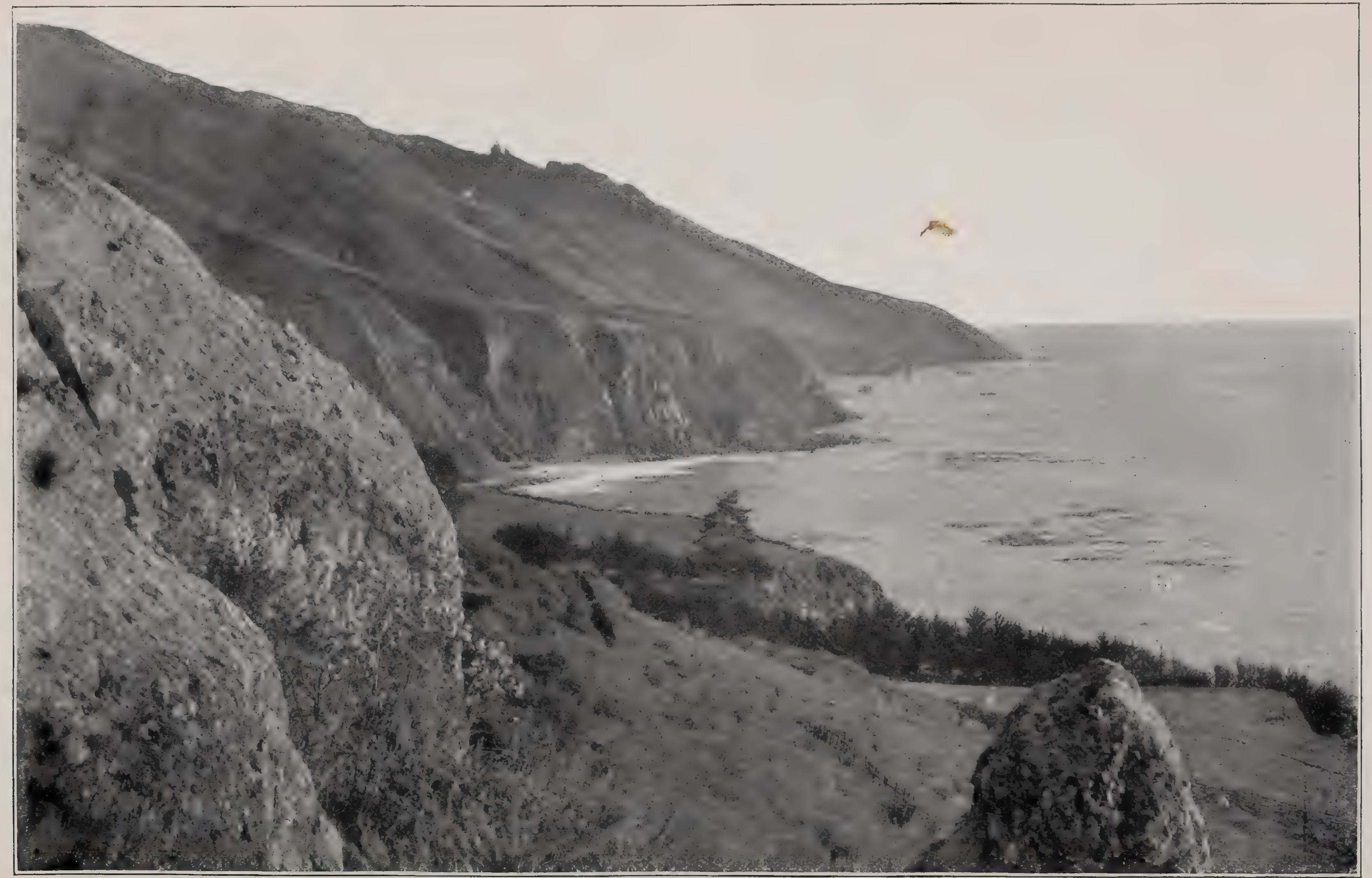
The stratigraphy of the Franciscan formation has not been ascertained in any of its outcrops. It comprises several lithologic varieties with a great range of character, from the coarse basal conglomerates to fine deposits, partly organic. The mass of the formation is sandstone and shale. A minor portion consists of radiolarian chert and limestone. In the section at Slate Springs the thickness exposed is, according to Fairbanks, about 1,500 feet, and grades from the basal conglomerate westward and upward into arenaceous black shales, with interbedded thin layers of sandstone.

FRANCISCAN GEOGRAPHIC CONDITIONS

In the presence of the Pacific, one does not question that it was the ocean whose waves wrought the Franciscan shore. The dip of the strata, though nearly vertical, is toward the Pacific, and bears out the immediate inference that it was the adjacent ocean in Franciscan time. Such was probably the fact; but as in later epochs a water body existed east of this position, apparently with a land area west of it, it should not be too confidently assumed that this Franciscan shore was certainly the then Pacific coast of the continent. It may have been the eastern coast of a western land.

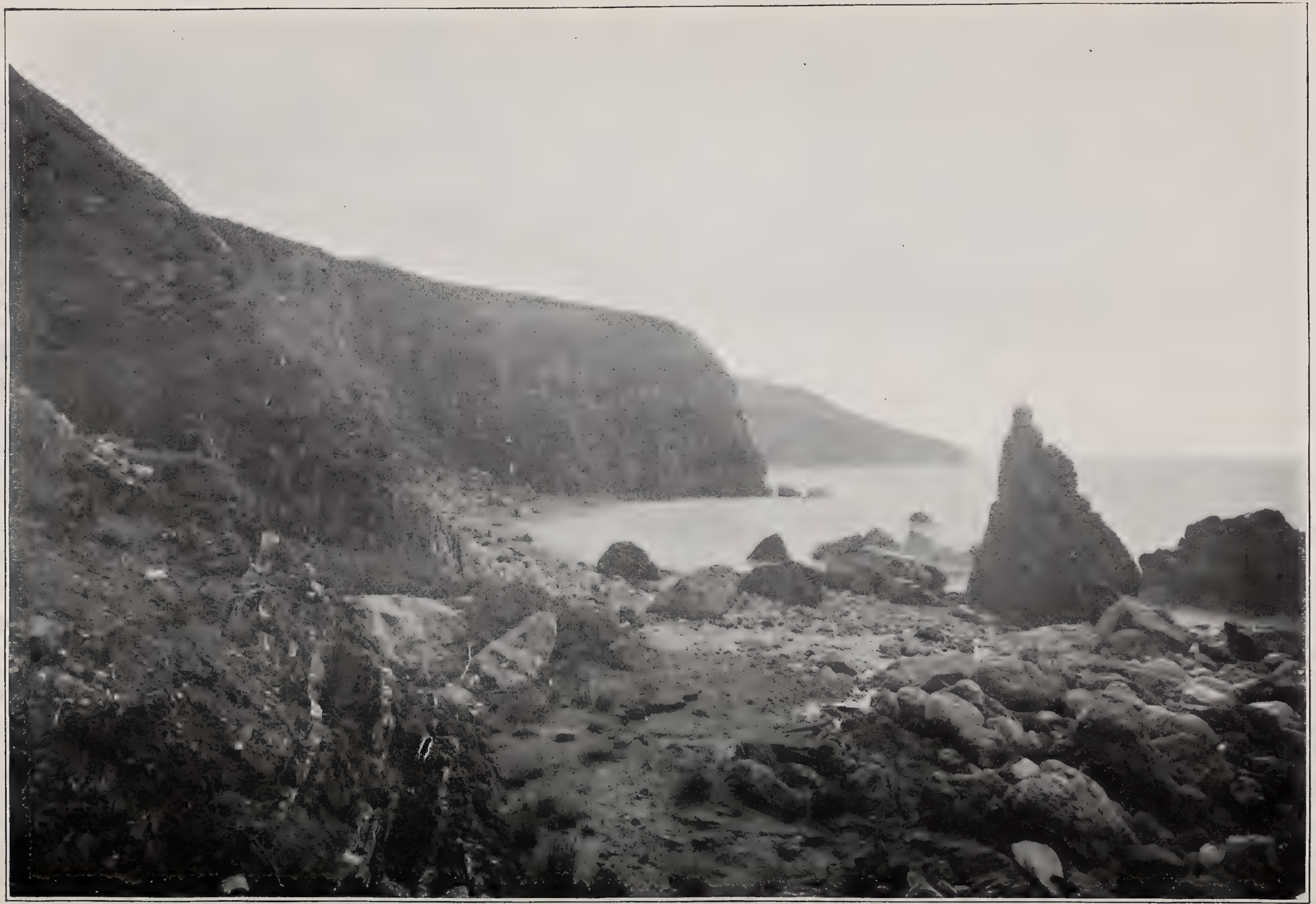
NATURE OF DEFORMATION

The structure of the Franciscan series is complex and among the associated formations characteristic. Deformation has been accomplished chiefly by fracture, with minor folding. The shales are generally plicated and broken at acute bends. The sandstones are broken and faulted. The cherts are crushed. In many instances the sandstones



COAST NEAR SLATE SPRINGS, CALIFORNIA

In the foreground are masses of basal conglomerate of Franciscan age. The sea-cliffs are cut in fossiliferous black shale (Franciscan) and extend to the Pleistocene terrace. The terraced profile of the distant tree-topped hill extends to about 1,200 feet above sea



COAST AT SLATE SPRINGS, CALIFORNIA

Showing structure of the Franciscan strata and sea-cliff cut in Pleistocene terrace

have been crushed into small fragments and recemented by silica, forming a lithologic variety which is in some degree characteristic of the formation. At Slate Springs the formation has been tilted into a nearly vertical attitude by northeast-southwest stress, and a distinct series of fractures and faults has been produced by a stress making a large angle with that which produced the general dip.

The complexity of the cross folding and faulting in the Franciscan series has prevented geologists from unraveling the detailed structure. The problem is apparently not more difficult than that presented in the Marquette iron region of lake Superior, and will yield to patient investigation. We shall then know whether there is one or several strata of radiolarian chert and limestone, and be able more adequately to understand the oscillations of sealevel which resulted in the variations of stratigraphy.

POST-FRANCISCAN HISTORY

CRETACEOUS LAND

Elsewhere succeeding the Franciscan in normal section occur several well known formations, namely, the Knoxville and Chico of the Cretaceous period, the Tejon (Eocene), and the Monterey (Miocene). Among these formations are several unconformities of greater or less significance and more or less widely extended occurrence. But in the region under discussion, the northern Santa Lucia range, several of the formations between the Franciscan and the Monterey are missing, and in the geologic record there is a corresponding hiatus which is significant of profound erosion. At Gamboa point, a few miles south of Slate Springs, the Franciscan formation occurs next to the ocean, extending from the shore up to an elevation of approximately 3,000 feet upon the spurs of the Santa Lucia range. The upper portion of the range east of this belt of Franciscan rocks is composed of the ancient Coast complex. Gneiss and marble constitute the summit at Twin peak and Cone peak, 4,700 and

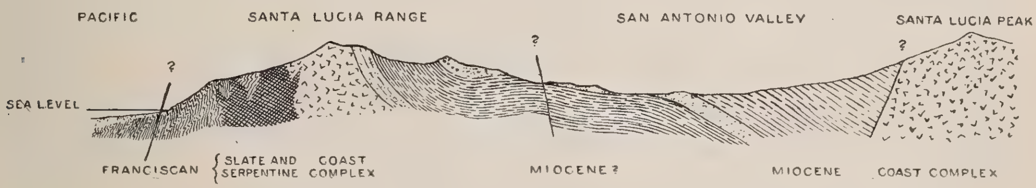


FIGURE 1.—*Generalized Section of Santa Lucia Range and San Antonio Valley.*

Taken from Gamboa point to Santa Lucia peak. The existence of the normal faults is inferred, not actually observed.

5,000 feet above the sea respectively. The spurs immediately east of the crest and almost equaling the highest points in elevation consist of a fine basal conglomerate of pebbles from the Coast complex and grade rapidly eastward and stratigraphically upward into sandstone and shale. These strata are very distinct from those of the Franciscan series outcropping a mile or two farther west. They are distinctly younger and of comparatively simple structural character. In the opinion of Doctor Fairbanks they are of Miocene age, since there is no unconformity between these formations and the characteristic shales of the Monterey formation overlying them. Some obscure fossils collected by Doctor Fairbanks and Doctor Palache from this locality have not been carefully determined. In this article the strata will accordingly be described as Miocene (?) provisionally.

MIOCENE (?) STRATIGRAPHY

Near the summit of the range the Miocene (?) strata have a steep northeastern dip, and descending eastward into the valley of the San Antonio river one traverses a section of three distinct lithologic members in ascending order. The lowest is the basal conglomerate already referred to as resting on the Coast complex, and continuous with it is an arenaceous formation consisting chiefly of coarse sandstone with some interbedded shale. This formation is roughly estimated to have a thickness of 800 to 1,000 feet. These sandstones are followed by several thousand feet of dark gray shale with occasional interbedded sandstone layers, and these in turn by several hundred feet of sandstone, which is coarse, ferruginous, and at certain horizons conglomeratic. This stratigraphic sequence presents a simple record of three steps: The first, a transgression of a sea upon an eroded surface of the Coast complex; the second, represented by the shales, a considerable subsidence of the sea bottom with concurrent deposition of fine material; the third, agencies of transportation, so invigorated as to once more contribute the coarse sands and pebbles to the sediment.

GEOGRAPHIC CONDITIONS OF THE MIOCENE (?)

A more detailed interpretation of the Miocene (?) stratigraphic record may be suggested as follows: In striking contrast to the very coarse conglomerate at the base of the Franciscan formation is the comparatively fine basal conglomerate of the Miocene (?) formations. The former consists of pebbles many inches in diameter—rolled fragments of fresh rocks. The other contains few pebbles as large as an inch or two across, and includes numerous subangular bits of feldspar and quartz from decayed rocks. Both conglomerates were derived from the Santa Lucia gneisses and granites. The evidence is equally direct that the Franciscan coast was abrupt and the Miocene (?) coast was plain. It also appears that waves beat heavily on the Franciscan cliffs and lapped gently on the Miocene (?) beaches. The proportions of the water bodies thus suggested are as the Pacific ocean and the bay of San Francisco.

The arenaceous formation which succeeds consecutively the basal conglomerate of the Miocene (?) group is of small volume and arkose composition. It is the product of erosion of a surface possessing only moderate elevation and relief.

The considerable mass of gray-black shale overlying the lower sandstone is sediment such as commonly gathers in estuaries similar to that which now deposits in the southern portion of San Francisco bay. If it be true, as will presently be suggested, that the Miocene (?) waters were in this district bounded on the west by a land, then the geographic place of this mud deposit may have resembled a larger San Francisco bay. The great thickness of the formation accumulated during and in consequence of equivalent subsidence.

The carious brown sandstone and conglomerate overlying the shale are in part probably not immediately derived from those crystalline rocks which originally furnished the sand and pebbles, although, in so far as the formation is an arkose, it does represent direct degradation of decayed rocks of the Coast complex. The conglomerate, however, is composed of pebbles of hard, enduring minerals, thoroughly rounded and worn, which apparently have been more than once transported from place to place of deposit. Together with the quartzose portion of the sands, they may be detritus of a coastal conglomerate or of alluvial cones. In contrast with the preceding sediment they indicate either more vigorous subaerial transportation or more energetic wave and current work, or both. By adequate study the significance of this member and of the two preceding it may be fully deciphered.

The structure of these Miocene (?) formations is that of a flexed monocline, the dips from Cone peak being toward the northeast and ranging from 70 degrees near the crest of the range to 5 in the eastern foothills. The attitude is suggested in the sketched section, figure 1. Some distant views indicated that gentle synclines were formed by southwestern dips about the head of San Antonio valley, but the observations were not conclusive.

RELATION OF THE MIOCENE (?) AND MIOCENE STRATA

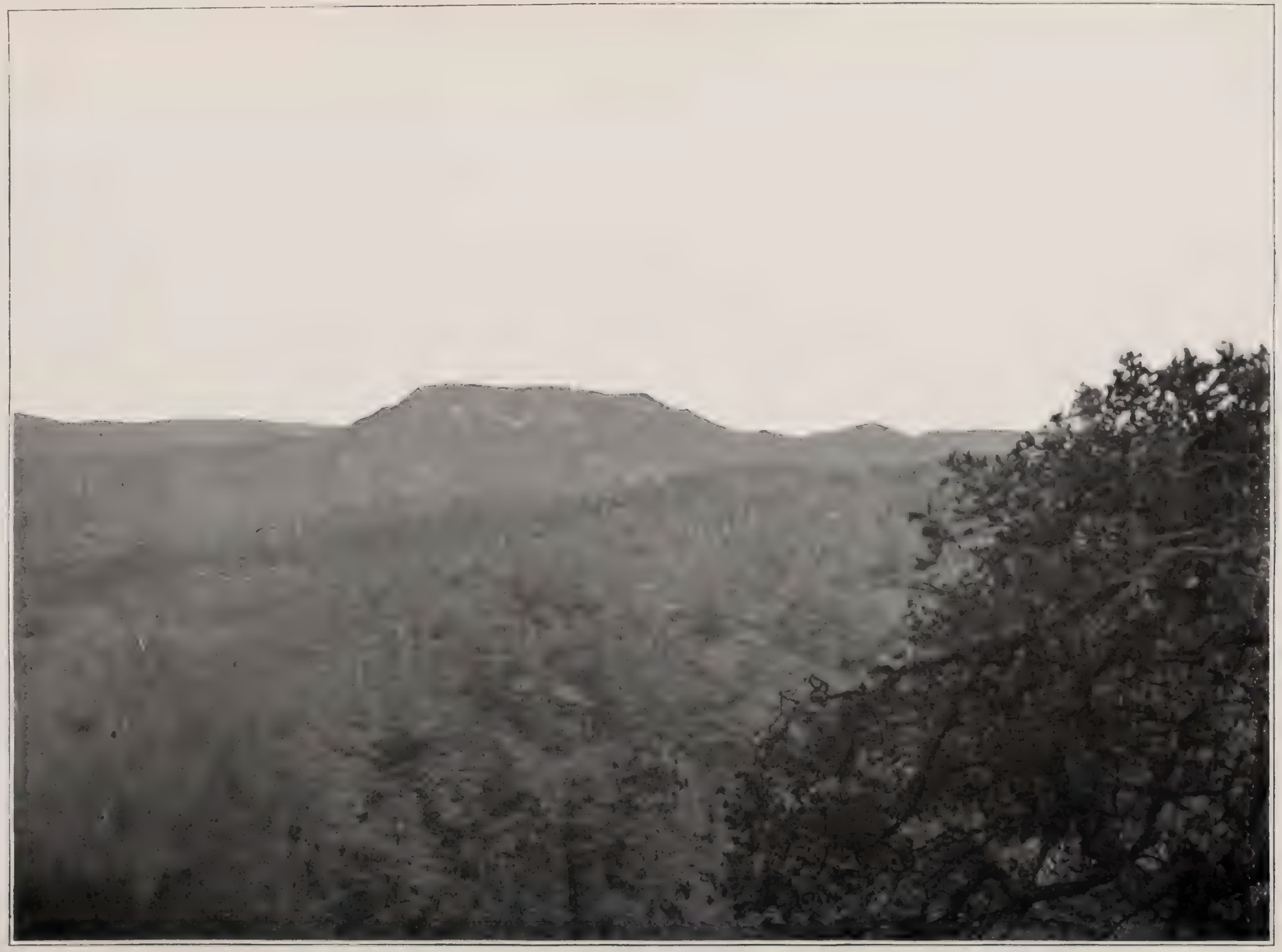
That range which has thus far in this paper been called Santa Lucia is the western of two ranges which bear the name. The western extends adjacent to the coast from point Sur to Morro bay (90 miles), where it turns eastward north of San Luis Obispo. A shorter range lies parallel with and 10 to 15 miles east of the western. Between them is the double valley of San Antonio and Nacimiento rivers. The eastern supports Santa Lucia peak (5,967 feet), the highest in either range. In this article it will be distinguished as the Santa Lucia Peak range.

Having descended over the Miocene (?) sandstone and shale on the eastern flank of the Santa Lucia range, the observer reaches the terraced flats of the San Antonio valley. Strata outcropping here and there through later gravels lie at low northeastern dips. East of the valley rises the Santa Lucia Peak range, its foothills composed of white shale characteristic of the Monterey (Miocene) formation. It also dips northeast, overlying the upper sandstone of the Miocene (?) group. Immediately east of the foothills rises the mass of the eastern range, composed of the ancient coast complex. The structural relation of the Monterey shale to these oldest rocks of the district forcibly suggests normal faulting, but the fault was not demonstrated by observation of the contact.

The course of the upper San Antonio valley is along the general strike of the Miocene rocks. At a certain point, however, the stream turns abruptly northeastward, flows through a short gorge in a low range of hills, and, entering a broad valley, resumes its course southeastward. The upper valley is opened in soft Miocene shale; the gorge is cut in crystallines of the Coast complex; the valley beyond it is developed in shale and sandstone which are of lower Miocene (?) or Miocene age. The basal member of the Miocene (?) group in this section is either wanting or is much finer, much less conspicuously a conglomeratic sandstone than it is 3 or 4 miles farther west. The upper coarse sandstone and conglomerate of the western outcrops also appears to be replaced by shale in part, if not entirely. Widespread gravel deposits generally obscure the strata in the lower San Antonio valley, but such outcrops as were observed were of shale. This apparent change in sediments takes place in a short distance (as is the case in a water body of moderate expanse) and offshore from a land which lay to the west; hence the inference that the coarser Miocene (?) sediments were derived from a western land beyond the crest of the Santa Lucia range. If so, that land is now submerged beneath the Pacific.

PINE MOUNTAIN SECTION; FRANCISCAN TO PLIOCENE

Where it was crossed in the vicinity of Cone peak the western Santa Lucia range has been described as exhibiting Miocene (?) strata on the eastern slope, rocks of the Coast complex in the summit and below on the west, and Franciscan at the western base. Thirty-four miles southeast of Cone peak the range was crossed a second time from Nacimiento



VIEW FROM PINE MOUNTAIN TOWARD PASO ROBLES, CALIFORNIA

Showing synclinal mountain of Pliocene and Miocene strata valley over Pine mountain to San Simeon. Franciscan strata with intrusives are the oldest rocks exposed in this section. Their outcrops extend from the Pacific to the eastern base of Pine mountain, a width of 10 miles or more. Overlying the Franciscan on the east, in the valley of the Nacimiento, are coarse conglomerate beds which closely resemble the upper conglomerate of the Miocene (?) group. White shale of the Monterey (Miocene) succeeds them and is in turn followed by the chalky San Pablo (marine Pliocene) strata. The Miocene and Pliocene* formations, including the conglomerate, are involved in an extensive synclinorium. The structure was obvious in the outcrops passed over en route and was traceable at a distance in consequence of the individuality of the Miocene (?) conglomerate and especially of the white San Pablo formation. A feature of the distant landscape east of Pine mountain is an isolated synclinal height in which San Pablo strata are maintained probably more than 2,500 feet above sea (see plate 28)

The magnitude of this synclinorium argues for its original development by simple subsidence before it was exaggerated and rendered complex by compression. Such a subsidence has already been inferred from the Miocene (?) formations. The broad facts of structure not only support the previous inference, but also define the areal extent of subsidence, inasmuch as the axis of the synclinorium trends with the axis of the original depression, northwest-southeast, and the anticlinorium of the western Santa Lucia range presumably coincides with a district which did not share or lagged behind the downward movement.

From the character and distribution of strata east of the Santa Lucia range and from their broad structural relations, it thus appears that the geographic conditions of Miocene and Pliocene time included a bay or strait northeast of a western land.

Pliocene to Present

PHYSIOGRAPHY OF THE COASTAL SLOPE

The western Santa Lucia range in the stretch of 60 miles from near point Sur to Pine mountain carries no strata younger than the Miocene (?) sandstones. If the district was submerged at any time subsequent to the Miocene (?), whatever sediments formed have been eroded. The history is therefore to be read in the physiographic aspects, of which the western slope of the range bears the more legible features.

To the writer's eye the Santa Lucia range presents two distinct stages of topographic development. An earlier is recorded in the aspects of higher slopes, including acute peaks, sharp ridges, and wide ravines. A later is suggested in the lower slopes by broad spurs, canyons, steep scarps, terrace remnants, and terraces, the sequence leading down to the present ocean level.

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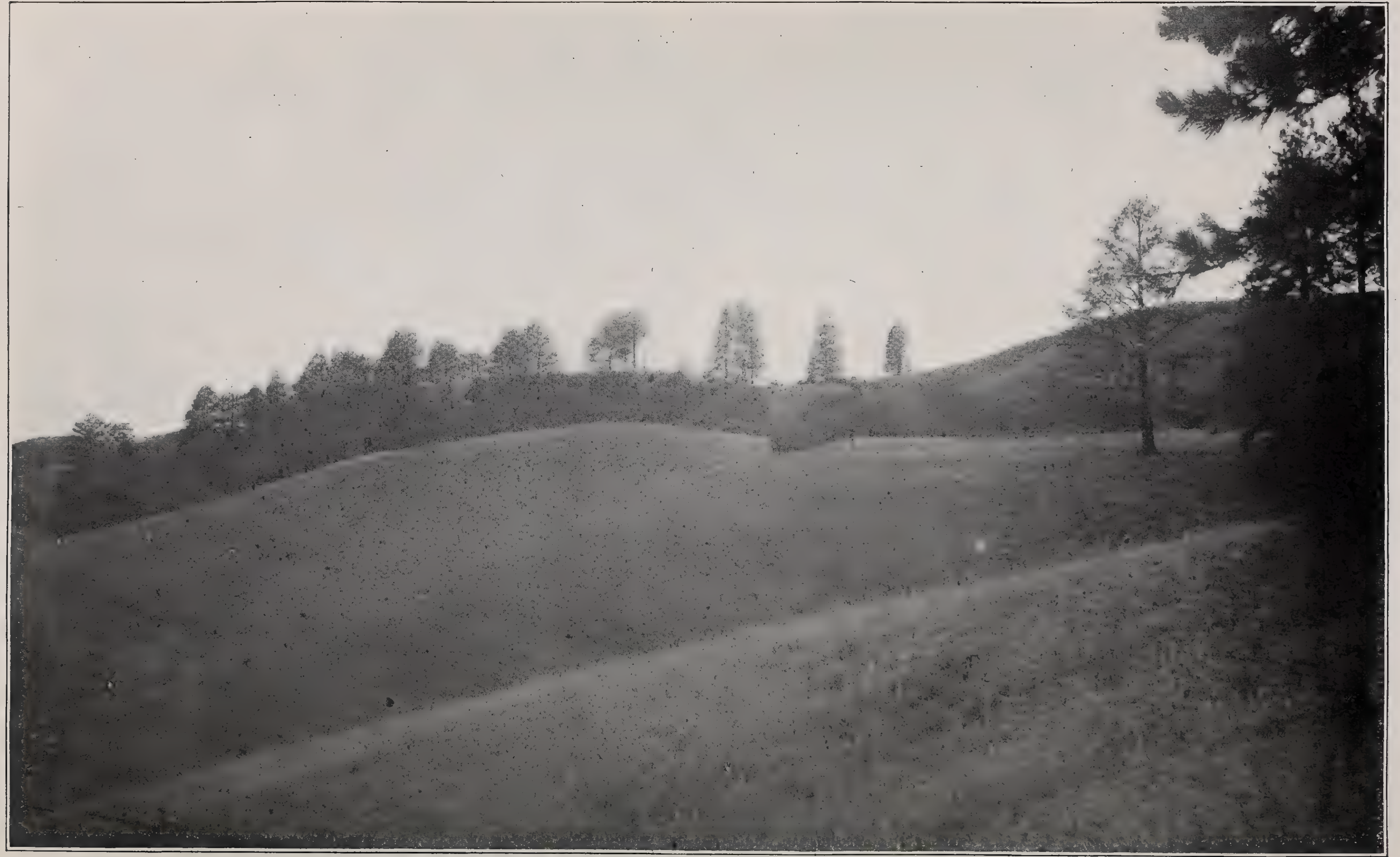
* Identified by Doctor Fairbanks.

The aspect of the higher slopes, above 3,200 feet, more or less, above sea, is that of advanced maturity. All forms are acutely developed. Rock masses are sharply distinguished according to resistance to erosion. There are practically no areas of gentle slope which might be considered as remnants of an earlier topographic surface.

At a certain elevation—that is, probably not far from 3.200 feet above sea—a great number of summits, ridges, and spurs fall into a level with the horizon. Nearly flat surfaces, which, though of moderate extent, are nevertheless inconsistent with existing conditions of energetic corrasion, survive here and there. This expanse of elevations is interpreted as evidence of an early lowland, a hilly lowland possibly, possibly a plain, above which the greater heights stood as monadnocks.

Below this certain elevation of approximately 3,200 feet the slope of the range toward the Pacific is comparatively gentle down to 2,000 feet or less above sea. Long spurs jut southwestward, descending at easy grades, or from bench to bench by steps. Between the spurs deep wide-gaping ravines are sunk, V-shaped. Approaching the ocean they become canyons. This description applies particularly to the spurs abreast of Gamboa point and to the Devils canyon. At 2,000 feet above sea, or thereabouts, the spurs end, some in prominent knobs, others in terrace remnants (see plate 29), and thence to the ocean the descent is distinctly steeper than it is from above. Locally for 1,500 feet the slope is probably as steep as 35 degrees. No lower spurs jut oceanward, but where canyons trend parallel to the coast narrow divides separate them from the Pacific. On these divides terrace remnants are preserved, as may be seen at Posts, between Big Sur valley and the ocean, at an elevation of 800 to 900 feet, and at the mouth of Devils canyon, 1,000 to 1,150 feet above sea. Other less conspicuous bits of terrace hang here and there on the steep slope. The final descent to the sea is locally by a precipice against whose foot the surf dashes. Elsewhere a terrace intervenes, 20 to 80 feet above sea, affording a strip of pasture land which may attain a width of 300 yards. This lowest terrace bears a heavy deposit of boulders and gravel, a conglomerate probably of Pleistocene age. Its face is usually too steep to climb from the beach (see plate 27).

As a working hypothesis, the writer offers the following reading of this physiography of the Santa Lucia range. The site of the Santa Lucia range was submerged in early Miocene (?) time and may have been so throughout later Miocene epochs, but a land area lay west of it. During



TERRACES AT GAMBOA POINT, CALIFORNIA

Approximately 2,000 feet above sea

some late Miocene or early Pliocene episode there developed an elevation such that the higher hills stood between several hundred and 2,000 feet above the then sealevel. They are now represented by the peaks 4,000 to 5,000 feet above sea, which have been described as monadnocks. During a long episode of constant sealevel, erosion produced a broad lowland that still may be recognized in the general approximation of summits and spurs to a uniform height of perhaps 3,200 feet. Renewed. uplift, amounting to 1,200 feet or more, led to partial dissection of the lowland plain and established the upper courses of the present ravines on the western slope. The streams discharging at a level which is now 2,000 feet above sea may have entered the ocean not far beyond, or at some distance west of the present coast. The features of the upper portion of the Santa Lucia range above 2,000 feet are apparently characteristic of subaerial development only. Benches of marine origin have not been detected, and the range may not have been a coast range during its earlier history.

Farther elevation of the range to its present altitude involved an uplift of 2,000 feet more. In referring to this movement as a later stage of development in comparison with the earlier evolution, there is no intention of describing it as a simple episode, but as the topographic features belonging to it are distinctly youthful, whereas those of the higher part of the range are mature, there are two distinguishable movements.

Among the features of the later stage, attention is especially drawn to the great scarp which rises from the ocean. Not everywhere equally bold, this scarp is most conspicuous south of the Devils canyon at Gamboa point, but in many remnants, which are only a little less modified than the gentler slopes, it still retains steeps of 30 to 35 degrees, and even of 40 degrees. On these the development of gullies and landslides gives abundant evidence of the process of recession which is reducing the slope. At the base sea cliffs here and there mark the opposite effect of the attack of the waves.

Among the various possible types of scarps there are but two whose genetic conditions are consistent with the environment of this one. They are the sea cliff and the fault scarp.* To distinguish them on this coast it is desirable to describe certain types of coastal slope which appear to differ in conditions of development.

THREE TYPES OF COASTAL SLOPES

Three types of coastal slopes may be distinguished between Santa Barbara and San Francisco, according to the dominant condition of modeling which determined the present aspect of the surface above the immediate coastline. A broad lowland borders the ocean about Santa Barbara, extending from the shore to the steeps of the adjacent coast range. Although elevated from 40 to 200 feet or more above sea, although traversed by incised streamways, although built up by alluvial cones from the mountain ravines, and in general modified by various subaerial agents, the lowland represents a plain of submarine origin. It is a section of sea-bed elevated slightly above sea. In the development of its dominant slope marine conditions controlled, whereas deformation and erosion only subordinately affected its present attitude and detail. This is the first of the three types referred to.

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* Gilbert: Monograph I, U. S. Geological Survey.

From Port Harford to point Buchon the San Luis range stretches near the coast. At its foot is a marked marine terrace, which fronts the immediate shore with sea cliffs from 20 to 80 feet in height and in places attains a width of half a mile. Being a wave-cut bench topped by coarse conglomerate, probably of Pleistocene age, this terrace belongs to the first type of coastal slope already described. From the back of the terrace the mountains rise 2,000 feet or more in spurs, between which are deep V-shaped ravines. The horizontal contours of the relief are those of softened maturity. The spurs are rounded, the ravines are acute. The contour curves are convex toward the sea and form sharply reentrant angles landward. Seen against the sky the profiles of the spurs are in agreement with the maturity of contours in general, but in detail they are marked by slight terrace facets. Traced horizontally these terraces are so continuous and nearly level that there is no doubt they are terraces of wave erosion. The most conspicuous one is approximately 700 feet above sea. The history of this coastal slope of the San Luis mountains is one of subaerial erosion, transient submergence, and emergence. The dominant activity by which it was sculptured was erosion. Marine erosion was a very subordinate influence. Deformation has had no effect upon its form, except as it has modified the conditions of the other two activities. This is the second of the three types of coastal slopes.

A third type is thought to be exemplified on the coast from point Sur to Piedras Blancas, and perhaps most strikingly at Gamboa point. The steep front which this coast presents oceanward has been described. Considered in a broad way, its horizontal contours are gentle curves, which are concave seaward and meet in prominent angles that are capes. The shoreline on the accompanying map illustrates this form, which, however, in detail is modified by the canyons cut across the scarp. Landslide benches and scarps and remnants of marine terraces are subordinate features of the slope. As has already been stated, this steep may have been either a sea-cliff or a fault scarp.

Considered as a sea-cliff, this scarp must be supposed to have been cut upon a gentler slope during its elevation from a submarine position. The work accomplished by the waves would much exceed that recorded upon the coastal front of the San Luis range, which lies nearly contiguous and exposed to the same attack. Marked terraces might be looked for as records of intermittent elevation, whereas only discontinuous and very local benches occur. The execution of such a task of cliff-cutting would require long time, the lapse of which should be recorded in the forms of subaerial sculpture, but the youthful aspects of the scarp and of the canyons traversing it do not bear out the inference. Thus the interpretation of this coastal slope as a modified sea-cliff is in several respects not in accord with facts.

Considered as a fault scarp, the feature is more readily understood, although the evidence of faulting is not conclusive. Steepness is an original character of a fault scarp, and may in this case be supposed to have limited the effect of wave erosion and to have been favorable to landslides. Thus the subordinate occurrence of marine terraces and the dominant concave contour characteristic of landslip scarps are explained. The canyons in which the mature ravines of the higher ranges terminate seaward are cuts in a coastal margin rapidly raised above baselevel, after the manner of a fault block elevated relatively to the downthrown block. The uniform trend of the coast for 60 miles, coterminous with the steep scarp, bears the character of a fault line. The test of this interpretation of the physiographic aspects may be the determination of the fault where it runs ashore. Northwestward it passes possibly east of point Sur, and thence beneath the ocean. The writer did not observe the geologic relations near point Sur. Southeastward the trend of the supposed fault strikes the shore near Piedras Blancas. The white rocks, which are described by the Spanish name, are of Miocene shale, and form a small area west of the Franciscan formation that extends from the coast across Pine mountain. This isolated patch of Miocene, Piedras Blancas, has the position of a downfaulted mass. The fault, not having been traced on the ground, can not, however, be said to be demonstrated.

The weight of physiographic and geologic evidence is clearly in favor of a structural origin for the bold scarp of the coast, at least from near Posts to Arroyo San Carpoforo, and it is therefore considered to constitute a third type, in the genesis of which deformation was the dominant activity, while erosion and marine sculpture played subordinate roles.

INCIDENTS IN THE SCARP-GROWTH

The rise of this scarp from ocean level was interrupted by a decided pause, which is marked in a group of marine terraces covering a space of 100 feet or more in altitude, and occurring at Posts 800 to 900 feet, at Devils canyon possibly 1,000 to 1,100 feet, and at point Buchon approximately 700 feet above sea. Their elevation at Posts is read from contours of Coast Survey chart number 5476. The other altitudes are based on aneroid readings of uncertain value. These terraces are more strongly marked and more generally present than any above or below them, and they have been correlated by Doctor Fairbanks with a general elevation of hill summits about San Luis Obispo and throughout an extensive area of the adjacent district.

Along the base of the scarp extend stretches of terrace now elevated 40 to 80 feet above sea, which are covered with heavy gravel deposits and are tentatively referred to the Pleistocene. No more definite date has yet been determined for them.

Between the monadnock, Cone peak, and the marine bench now being cut in the base of the scarp, there is thus a physiographic record of the uplift of the Santa Lucia range. The history covers Pliocene and Pleistocene time to the present. Marked features of the physiography are the high monadnocks, the upper dissected plain at 3,200 feet above sea, the lower dissected plain and correlated terraces at 700 to 1,000 feet above sea, and the Pleistocene terrace; but the most striking physiographic feature is the great fault-scarp, if such be its true character, dividing the upraised mountain block of the Santa Lucia range from the downthrown mass of the western land, which is submerged beneath the Pacific.

Future observers will trace out relations between the various physiographic features and the marine and fresh-water deposits of post-Miocene age. The sedimentary and physiographic records are both fairly continuous and legible in the interior valleys as well as along the coast, and will yield a connected history of the Coast ranges when studied in detail with adequate maps.

SUMMARY

The outline of the history since the earliest geologic conditions recorded is summarized in the accompanying diagram; but one salient fact needs here to be emphasized: Along this farthest Pacific margin of the continent the present coast occupies a position across which coasts of earlier ages have repeatedly migrated, as land or sea for the time being prevailed. The student of continental growth finds no evidence of permanent encroachment of continent or ocean either upon the other. The student of mountain growth, however, finds an example of the general law that the site of an existing mountain range has been occupied in past ages by successive generations of mountain ranges.

Explanation of Figure 2

Conventions used in diagram.—Time is represented in sequence from left to right. As the total lapse of ages represented by the record is unknown and the relative durations of successive ages are indeterminate, there is no definite time scale; but that portion of pre-Franciscan time represented was probably much longer than post-Franciscan time. The time scale is therefore much smaller at the left than at the right of the diagram.

Vertical ordinates represent positions in the earth's superficial crust from a mile above sealevel to 6 miles below sealevel. Sealevel is arbitrarily taken as a fixed datum.

Sequence of sea and land.—The upper curve represents from age to age the varying relation of the rock surface to sealevel in the chosen locality. Below sealevel the position of this line results from the amount of subsidence, less the thickness of deposits. Above sealevel its position is determined by the amount of uplift, less the effect of erosion. The values indicated are to be taken qualitatively, not quantitatively. The following is the interpretation of the several lettered sections:

a–b. Submergence; sedimentation corresponding to the strata of the Coast complex; comprising epochs probably of great duration and of complex physical changes; probably closed by orogenic movements that resulted in folding of the Coast complex in the zone of deformation by flow, and were connected with granitic intrusions.

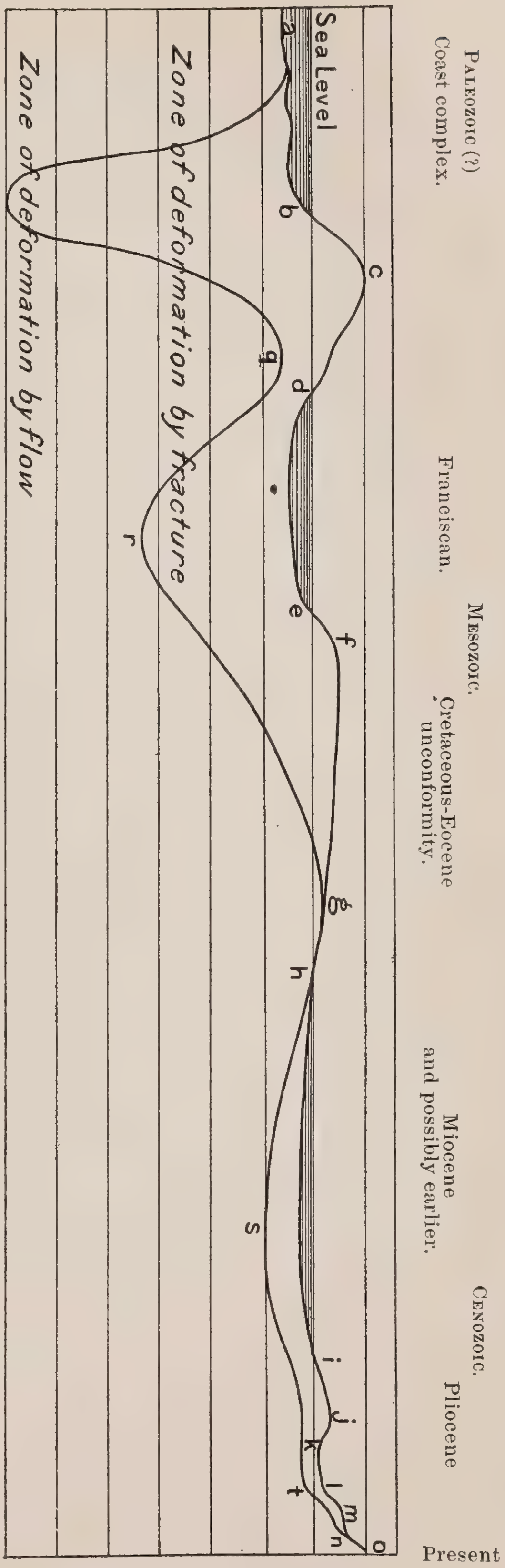
Paleozoic (?)
Coast complex.
Franciscan.
Mesozoic.
Cretaceous-Eocene unconformity.
Miocene and possibly earlier.
Cenozoic.
Pliocene
Present
Sea Level
Zone of deformation by fracture
Zone of deformation by flow
a
b
c
d
e
f
g
h
i
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Figure 2.—*Diagrammatic Summary of Orogenic Movements for the District of the Northern Santa Lucia Range from Paleozoic Time to the Present.*

b-c-d. Emergence; erosion which sufficed to lay bare metamorphic schists and granite of the Coast complex, so that these rocks entered the basal conglomerate of the Franciscan series at the time *d.*

d-e. Submergence; sedimentation corresponding to the Franciscan series, of late Juratrias or early Cretaceous date; closed by movements which gave rise to deformation of the Franciscan series in the zone of deformation by fracture.

e-f-g-h. Emergence; erosion following the initial uplift and probably other movements corresponding to unconformities among Cretaceous and Eocene formations of adjacent sections.

h-i. Submergence; sedimentation corresponding to the formations of Miocene (?) and possibly later Miocene (Monterey) time, limited at an indeterminate date by the initial rise of the present Santa Lucia range, but continued into Pliocene time in the adjacent eastern district.

i-j. Emergence; corresponding to the initial rise of the Santa Lucia range; approximately 1,800 feet.

j-k-l. Pause in uplift, resulting in erosion to general lowland with monadnocks.

l-m-n. Renewed uplift (1,200 feet ±) and erosion, with development of high level terraces, now 2,000 feet ± above sea at Gamboa point.

n-o. Later elevation of the Santa Lucia range, a rise of 2,000 feet, probably associated with development of coastal fault scarp. This later movement may have been complicated by or succeeded by oscillations of level of several hundred feet, apparently recorded in the San Luis Obispo district.

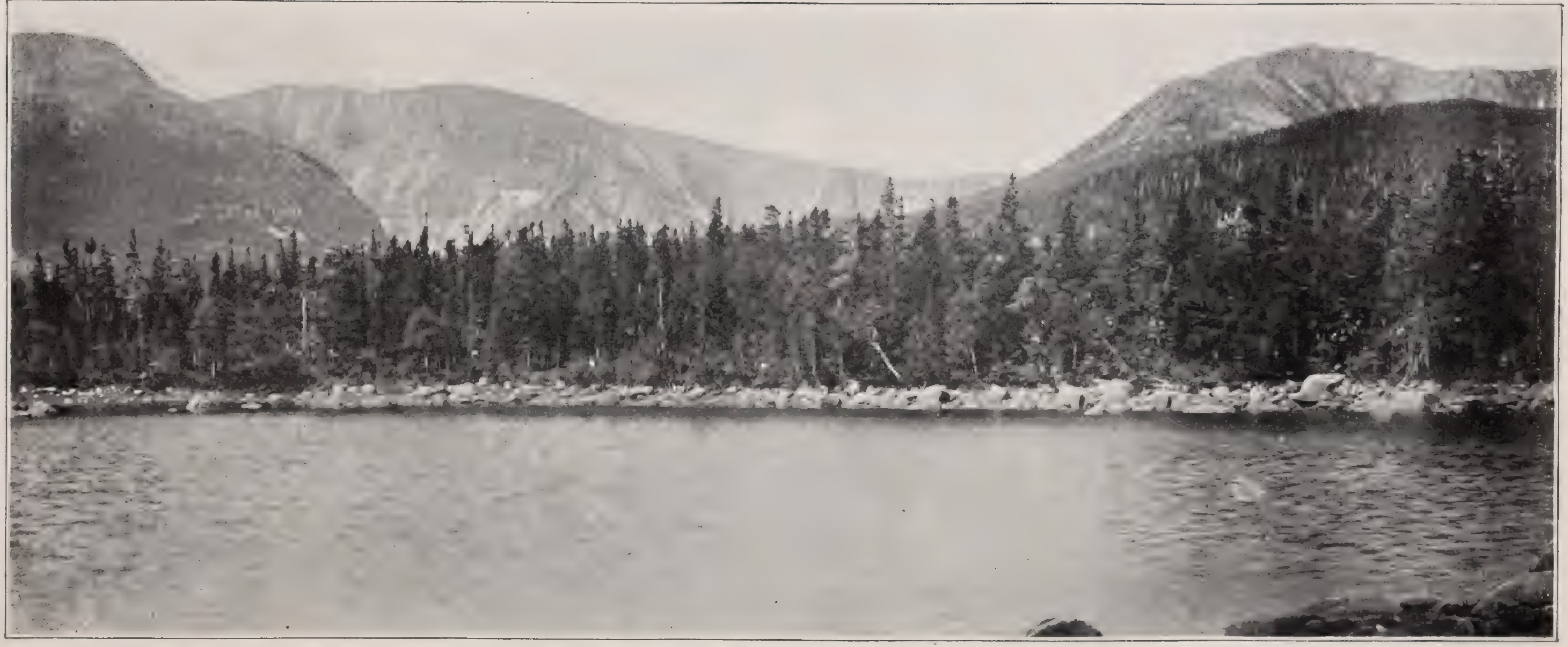
Path of Coast complex stratum.—At the right of the diagram at *o* is represented a point near Cone peak, 5,000 feet above sea, where there is an outcrop of marble and gneisses of the Coast complex. The lower curve represents the path of these sediments from their place of deposition in the Paleozoic (?) sea across the zones of the earth's crust to their present position.

a-p. Subsidence; which carried the strata of the Coast complex down to the zone of deformation by flow.

p-q. Uplift, accompanied by movements of compression and granite intrusion.

q-r. Subsidence, corresponding to burial beneath Franciscan sediments.

r-g-h. Uplift accompanied by deformation of Franciscan formation and volcanic activity, probably distributed in several episodes with quiescent intervals. At *g* the particular strata of the Coast complex which now outcrop at *o* are assumed to be exposed and to form part of the surface upon which the Miocene (?) sediments were deposited.



MOUNT KTAADN, MAINE

As seen from the morainic wall which encloses one of the ponds near the entrance to the South basin. North basin is on extreme right, behind the ridge

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GLACIATION OF MOUNT KTAADN, MAINE*

BY R. S. TARR

(*Presented before the Society December 30, 1899*)

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NATURE OF THE WORK

In 1897 I spent a month among the mountains of the highland region of Maine, ascending a number of the higher peaks, notably mount Abraham, in the Dead River plantation, and mount Ktaadn. The chief object of this expedition was to satisfy myself, from personal study, as to the probable succession of events near the close of the Glacial Period in the New England region.

Some American writers have called attention to the evidence of local glaciation among the New England mountains, but of late years very little has been done toward a study of these phenomena. Evidence has also been brought forward seeming to prove that the continental glacier passed from Canada across the Saint Lawrence and over the highest New England mountains; yet certain Canadian geologists have held that the Labrador glacier did *not* cross the Saint Lawrence valley and invade the New England states, but that, on the contrary, glaciers spread out from separate centers, both from New England and Labrador, reaching toward and into the Saint Lawrence valley. The facts which the Canadian geologists have brought forward in support of this view, together with the evidence of local glaciation observed by Agassiz, Hitchcock, and others, seemed to me to call for careful consideration.

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* In this work I was assisted in 1897 by R. D. Evans and R. P. Tarr and in 1899 by J. O. Martin and F. S. Mills, all Cornell students.

In 1897 the expedition was devoted to a general study of the highland region of Maine, during which opportunity for detailed work in a single locality could not be found; but certain phenomena suggesting local glaciers in the neighborhood of Ktaadn were seen during this first expedition and were made the object of a second expedition in June, 1899, about ten days being spent in the woods at the eastern base of mount Ktaadn. Only a small region could be covered during the time available, for the difficulties in the way of geological study in the woods of Maine are immense. Much of the traveling from place to place consists of long detours in order to take advantage of trails and water-courses, and when one leaves the beaten path he knows not what swampy tracts, tangles of "blow-downs," or the still more difficult "pucker-bush" he may encounter. Even where the way is fairly open and clear, the surface is so completely covered with timber that details of land form are exceedingly difficult to work out. Indeed, Hamlin stated that—

> "Entirely satisfactory determination of the nature of these ridges is impossible while they are, as at present, completely masked by dense thickets; but should fire hereafter lay them bare, opportunity will be afforded for thorough examination before a new growth springs up."

While it is not necessary, as Hamlin has suggested, for fires to clear the surface in order that proof of valley glaciers may be seen, it is safe to say that no very large amount of detailed work in glacial geology will be possible in this part of Maine so long as the present forest cover obscures the surface.

During the two expeditions, aside from a visit to other parts of Maine, including the ascent of several mountains, Ktaadn was ascended four times along different routes, and a part of the region near the eastern base was carefully examined.

Glaciation of the high Mountains

From the Adirondacks eastward and northeastward, far up into northeastern Maine, there is a mountain barrier, broken here and there by numerous low passes. From this highland region northward the land descends by a distinct slope to the Saint Lawrence, and then rises toward the Labrador region, where there is a highland of moderate elevation.

It is natural to suppose that such a barrier would have interfered with the passage of a glacier having its origin in the Labrador region. In fact, one of the most difficult conceptions that I have had to consider in glacial geology is that of the passage of an ice-sheet over a highland barrier of such extent and elevation as that of New England; yet proof of this passage seemed complete. Evidence from the Adirondacks and from the Green mountains* shows that the ice-sheet rose well up toward the top of these mountains, if in fact it did not override the highest peaks. In the White mountains, the highest of all in this mountain-barrier region, Hitchcock† has found transported pebbles at the height of 6,100 feet. On mount Ktaadn transported fragments have been found by different observers at various elevations, although Hamlin,‡ who found them at the highest point, did not discover any above an elevation of 4,615 feet. Indeed Upham, from his study of the literature,§ announces that Ktaadn projected its peak above the *mer de glace.*

To this evidence of previous workers I am able to add one or two further observations concerning the glaciation of the high mountain tops of New England. About midway between Ktaadn and mount Washington, in the Dead River plantation, is a mountain called mount Abraham, which reaches an elevation of about 4,000 feet. From its crest mount Washington may be seen to the southwest and mount Ktaadn to the northeast. This peak rises distinctly higher than any of the surrounding mountains, and in fact is one of the highest in Maine. On its crest are found not only numerous small fragments of transported rock, but even large boulders. One particularly large foreign erratic, several tons in weight, may be seen along the trail; and on the very crest, near the cairn, I picked up several distinctly foreign pebbles of a stratified rock, entirely different from the gneissic and schistose layers of the mountain itself.

While ascents of other lower mountains were made, and in each case transported fragments found, one does not need to climb to the crests of these lower peaks in order to obtain evidence that they were overridden by an ice-sheet moving from the north. Their form proves this conclusively, for the stoss side is strikingly smooth and rounded, while the lee side is prevailingly steep, and at times very precipitous. This is so prominent that it attracted the attention of Thoreau during his journeys through the Maine woods. Further reference is made to this feature of the mountains in a latter part of this paper.

During the first ascent of mount Ktaadn the highest peak was not reached. While the ascent of the high North peak was being made the clouds closed in around the still higher South peak; but on this climb many transported pebbles were found on the north peaks, the highest of which is 4,700 feet in elevation. The second expedition to the top of the mountain was over Pamola (see plate 31), which is also distinctly lower than South peak. While a careful search for transported pebbles was not made there, because the mountain is so much lower than South peak, the fact that in making this journey none were seen would prove that they are at least much less abundant than on North and South peaks; for one does not need to search with marked care on these peaks in order to find transported fragments. The only explanation that I am able to suggest for their scarcity or absence from Pamola is the prevailing steepness of the slope in all directions, which might well have permitted the larger number of imported fragments to have been carried away since the ice left them there. The more gentle slope of the crests of North and South peaks is much more favorable to the retention of these transported fragments.

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*Upham: Amer. Geologist, vol. iv, 1889, pp. 165 and 205.

†Proc. Amer. Assoc. Adv. Sci., vol. xxiv, part ii, 1875, pp. 92–96.

‡Bull. Museum Comp. Zoology, vol. vii, 1881, pp. 189–223.

§Upham: Amer. Geologist, vol. iv, 1889, pp. 165 and 205.

On the third expedition to the top of mount Ktaadn, which by one measurement was shown to have an elevation of 5,150 feet,* both Mr Martin and I found transported pebbles all the way from the base of South peak to its very crest. In the course of the climb from the plateau to the crest of South peak, no less than two or three hundred transported fragments were seen. They were so numerous that we did not find it necessary to search carefully for them, and on reaching the crest, within 20 feet of the cairn marking the highest point on Ktaadn, three fragments were found, and others could doubtless have been obtained had we searched for them.

The mountain, as shown by Hamlin, consists entirely of granite, which in unprotected portions has been much disintegrated by frost. There are places where one travels entirely on these broken fragments of Ktaadn granite. This is especially true of the serrated and very rough ridge between South peak (East peak of Hamlin, plate 31) and Pamola, where one would doubtless have difficulty in finding foreign pebbles. South peak (West peak of Hamlin, plate 31) slopes rather gently toward the north; in fact, there are patches on it where the granite rock is partially covered, and it was in these places that the foreign pebbles were found to be most abundant. They consist in some cases of schists, in others of slaty rocks resembling argillite, and in still others of sandstones. There can be no question as to their derivation from a distance, and this derivation must

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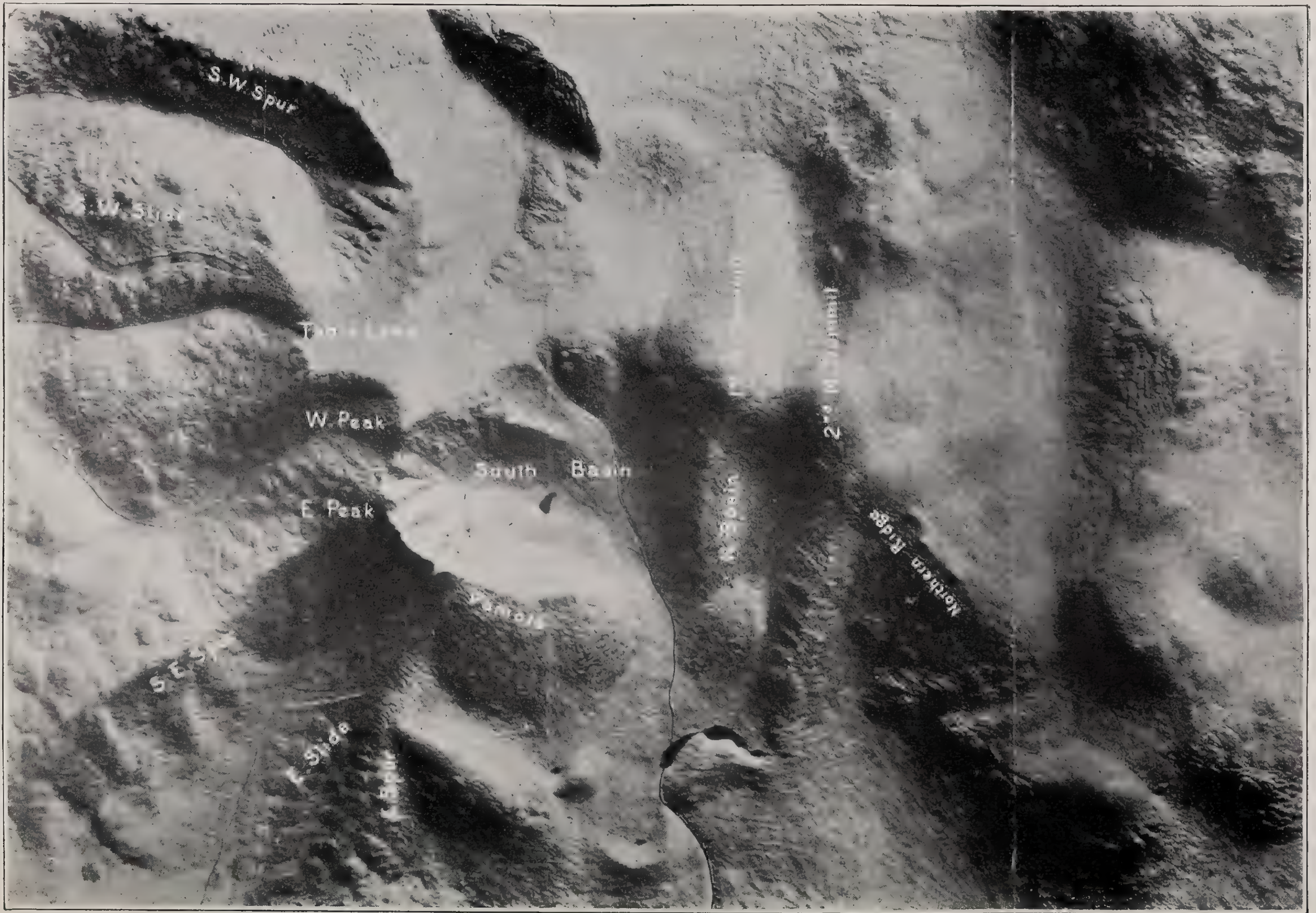
*The elevation of the mountain was obtained by an aneroid, with corrections for variations in atmospheric pressure. In making the corrections the record kept at the nearest weather bureau station, at Eastport, Maine, was used. Owing to the distance between Ktaadn and Eastport, this measurement can not be considered to be accurate, though it differs from Fernald's by only 65 feet. The other elevations were also made by aneroid, but the time occupied in making them was so brief that they may be considered to be approximately correct.



HAMLIN'S MODEL OF KTAADN AND VICINITY

have been from a lower point. To the north of Ktaadn there are metamorphic and stratified rocks similar to these, and the origin of the fragments is naturally inferred to be from that source.

It seems hardly necessary at the present time to state the reason for assuming a northern origin rather than some other; yet since there are some who might perhaps suggest that Ktaadn was glaciated from the high mountains of northern New Hampshire, a word may be said on this point. The White mountains are the only other highland in New England from which glaciers could originate that could cover Ktaadn; but this source is proved to be impossible by the striæ and by the shape of the glaciated hills, all of which point to a north-south movement of the ice.

From this study it is proved that even Ktaadn did not rise above the glacier during its maximum extent, as has been assumed. The reasons for the belief that Ktaadn reached above the ice have been, first, the authority of previous observers, who have not discovered transported fragments upon the highest points, and, secondly, the marked angularity and ruggedness of portions of the crest of mount Ktaadn, especially that between South peak and Pamola.

The discovery of foreign fragments on the highest point settles the question as to the ice covering, but a further word concerning angularity of mountain crests may not be out of place. The angular, rugged part of Ktaadn is not only above the zone of trees, but its topography is such as to permit rapid disintegration. It is really a ridge, in places so narrow that when the wind blows strongly, people who have crossed from South peak to Pamola have been known to crawl on their hands and knees. Under such conditions frost action works rapidly, since the fragments loosened are quickly removed by wind or water, and the breaking up of the granite naturally produces a ruggedness of the surface.

Another reason for the ruggedness is the fact that this part of the mountain was somewhat protected from ice action by the barrier of the North and South peaks, so that it did not receive much scouring and rounding. Indeed the entire crest of Ktaadn could not have been greatly eroded, because it rose high up into the ice above the zone of maximum ice erosion. Doubtless the glacial currents swept around Ktaadn, as we know that they do around partially and completely buried nunataks in the Greenland glacier. Moreover, these high points have been long exposed, having for a while projected as nunataks above the surface of the surrounding ice-sheet, so that weathering and erosion have been able to produce much more distinct effects than on the lower mountains, which were covered by the ice for a longer time, and most of which are now protected by a timber cover.

But even without considering these latter causes for angularity of high peaks, one does not need to marvel that an elevated mountain ridge, narrow and projecting above the timber line, should have been rendered rugged by the rapid erosion which is in progress on lofty mountain tops.

From the observations that have been brought forward by different observers, there appears no escape from the conclusion that an ice-sheet moving from the north overtopped the highest peaks of the Adirondacks, the loftiest mountains among the Green mountains, mount Washington, mount Ktaadn, and all the lower mountains of northern New England. Here is a perfect cordon of mountain peaks, a barrier to the on-moving ice-sheet, but nevertheless overcome by it; and it appears certain that the facts which the Canadian geologists have brought forward must be explained in some other way than by the elimination of the continental glacier. I believe that its explanation is at hand, having been suggested by Hitchcock, although little attention seems to have been paid to the suggestion.*

PREVIOUS ANNOUNCEMENTS OF VALLEY GLACIERS

A number of observers have presented evidence of former valley glaciers among the mountains of New England, especially in the early days of the study of glacial geology, though of late years very little work has been done in that direction. Doubtless some of these early observations were based on the confusion of deposits from the main ice-sheet with those from supposed valley glaciers; but other observations certainly represent accurate correlation of glacial deposits with valley glaciers. Among the suggestions of local glaciers in New England one of the very earliest was that of Edward Hitchcock.† Professor C. H. Hitchcock ‡ has published further proof of ancient glaciers in Maine and Vermont. In later publications § Professor C. H. Hitchcock has again and again presented evidence of local glaciers in New England, and in his latest paper, || in which he has once more called attention to the evidence of glaciation in the Green mountains and the mountains of New Hampshire and of Maine, he suggests the possibility of the contemporaneity of local glaciers, from several large centers, with the "Champlain" depression of the land in the Saint Lawrence valley. The work of Hitchcock in

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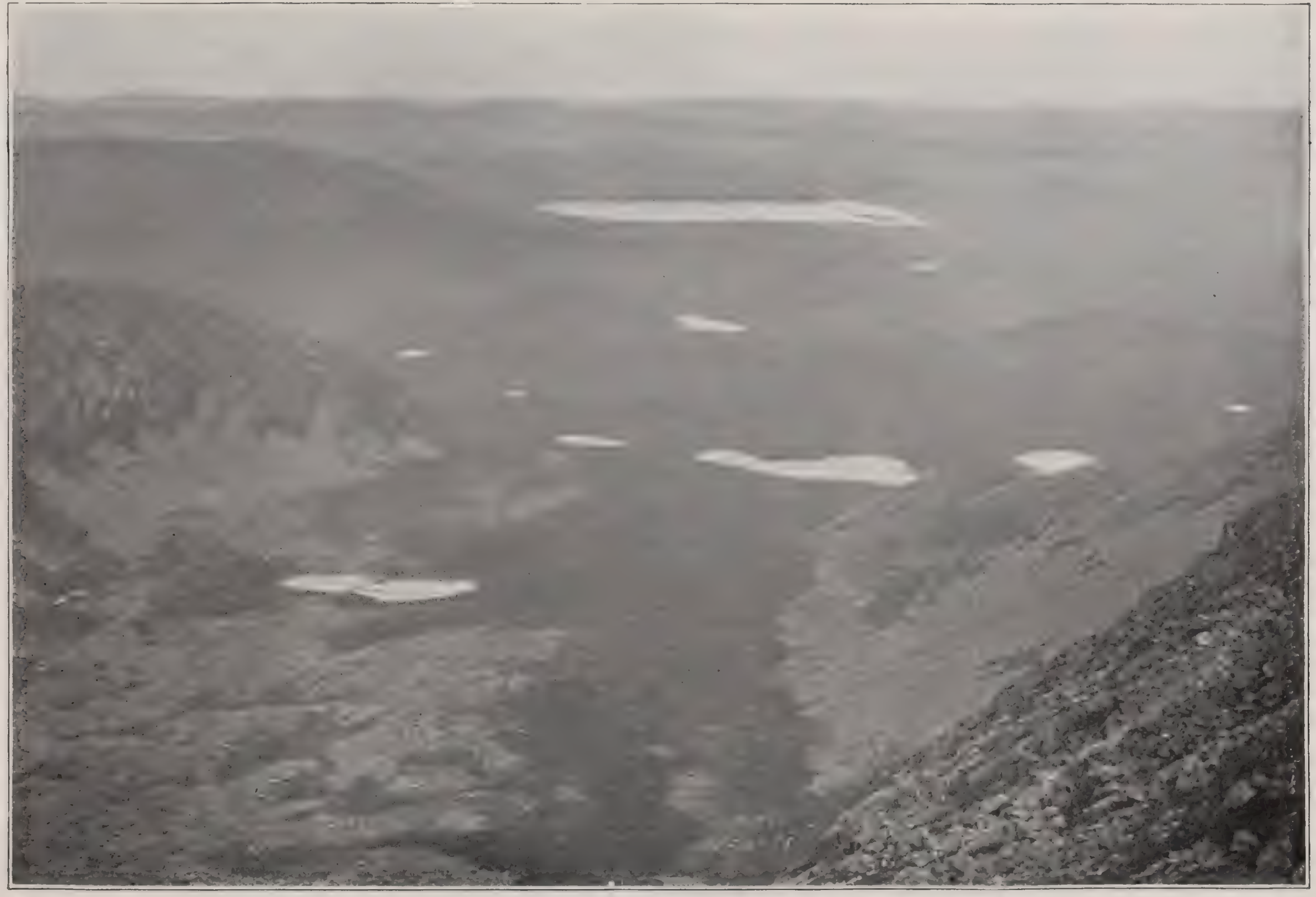
* Bull. Geol. Soc. Am., vol. 7, 1896, pp. 3, 4.

† Smithsonian Contributions, vol. ix, 1856, art. iii, p. 136.

‡ Proc. Amer. Assoc. Adv. Sci., vol. xiii, 1859, pp. 329–335.

§ Geology of New Hampshire, vol. i, 1874, pp. 539–544; same, vol. iii, 1878, pp. 181–340; Proc. Amer. Assoc. Adv. Sci., vol. xxiv, part ii, 1875, pp. 92–96; Bull. Geol. Soc. Am., vol. 7, 1896, pp. 3, 4; Preliminary Report on the Natural History and Geology of Maine (Sixth Ann. Rept. Maine Board of Agriculture, 1861), p. 393.

|| Bull. Geol. Soc. Am., vol. 7, 1896, pp. 3, 4.



NORTH BASIN FROM NORTH PEAK

View is taken looking down North Basin and shows the chain of moraine-dammed ponds this connection, especially that in his Geology of New Hampshire, will, when the glacial geology of New England is more fully worked out, need to be considered as a prominent contribution to glacial geology.

When Agassiz first came to this country he detected what he believed to be evidence of valley glaciers among the mountains of New England, and, though he did not until later publish fully upon them, he was one of the first to definitely suggest valley glaciers for that region. His papers on that subject* contain one of the clearest statements of the evidence of these valley glaciers that I have seen, and, granting the correctness of his observations, they would seem to prove conclusively that such glaciers did exist there. Important contributions to the subject of valley glaciers in these mountains have been made by Packard,† Vose,‡ and Dana.§ The latter author assigns many of the so-called evidences of valley glaciers to the influence of topography upon the ice currents.

Hamlin || suggests that the location of a chain of three ponds (plate 31) near the foot of mount Ktaadn is significant of local glaciers, being situated just where terminal moraines of glaciers issuing from the basins would naturally occur. He concludes, however, that entirely satisfactory determination of these deposits is impossible while they are so completely masked by dense thickets. This suggestion of valley glaciers, made by Hamlin, naturally occurs to one as he looks from the top of Ktaadn into the North and South basins and notes the tiny ponds, apparently nestling in the midst of an irregular morainic topography (see plate 32.) This suggestion likewise occurred to me during my first visit to Ktaadn, and it was primarily for the study of this region that I returned to Ktaadn in 1899.

TOPOGRAPHY OF MOUNT KTAADN

The general topographic features of Ktaadn are well illustrated in Hamlin's model, which is here reproduced (see plate 31) from an illustration in his paper referred to above. The mountain rises far above the elevation of any surrounding land, reaching well above the timber line. From the north side the ascent is rather gradual, but from the south side the mountain rises as a great block from the lowland of the West branch of the Penobscot, the grandest mountain in New England.

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* Proc. Amer. Assoc. Adv. Sci., vol. xix, 1870, pp. 161-167 (reprinted in Amer. Naturalist, vol. iv, 1871, pp. 550-558); Geological Sketches, vol. ii, 1890, pp. 101-152.

† Amer. Jour. Sci., vol. xliii, 1867, pp. 42; Amer. Nat., vol. i, 1868, pp. 260-269.

‡ Amer. Nat., vol. ii, 1869, pp. 281-291.

§ Amer. Jour. Sci., ser. iii, vol. ii, 1871, pp. 233-243, 305; same, vol. v, 1873, p. 198.

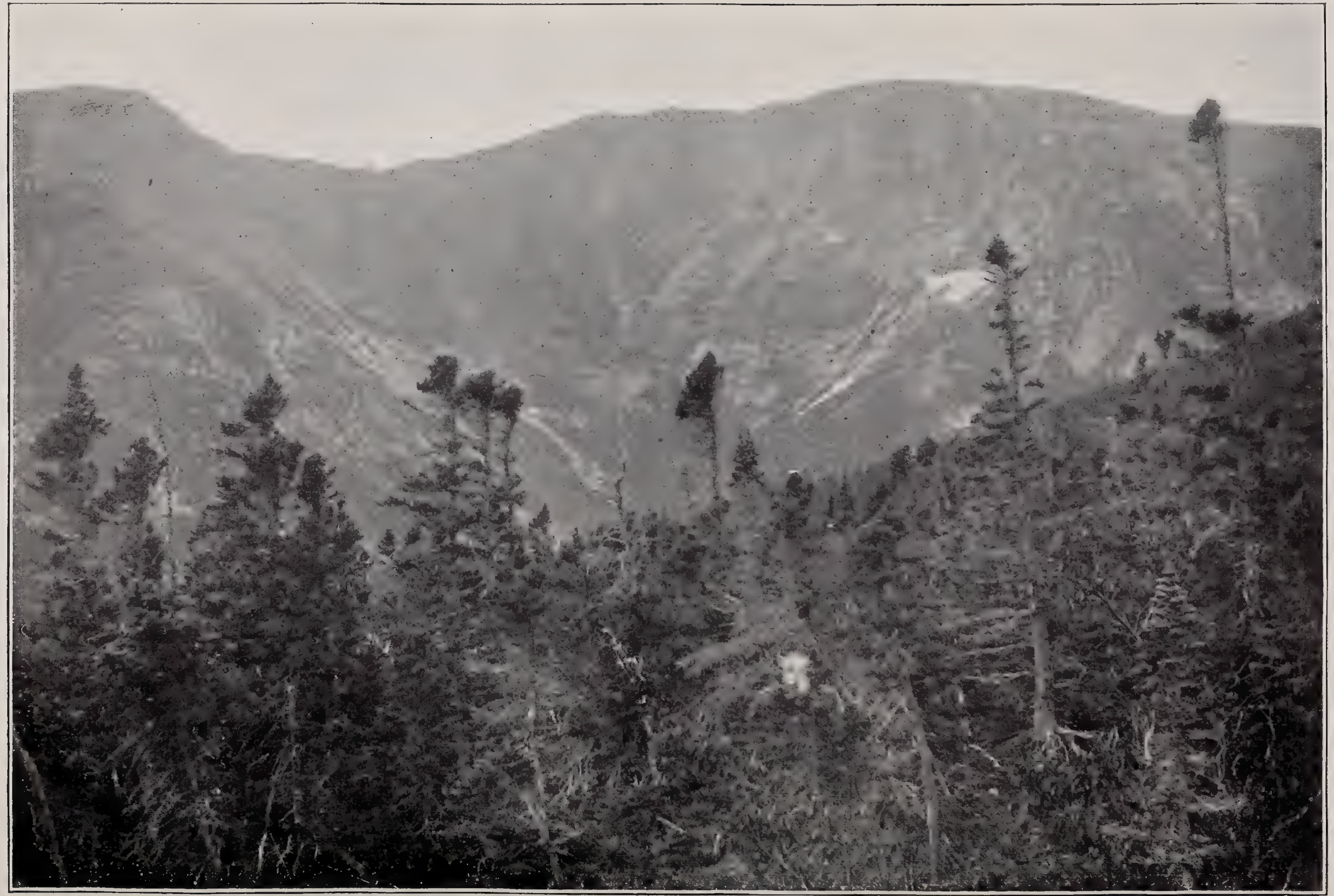
|| Bull. Museum Comp. Zoology, vol. vii, 1881, p. 219.

The main part of the elevated portion of the mountain is occupied by the "tableland" (see plate 31), from which several spurs extend as divides between stream valleys heading on the mountain top. In places this tableland is remarkably level; but on the northern side it gradually merges into a zone of moderate irregularity, beyond which there are four peaks—the North peaks, located on the crest of a broad ridge. The northernmost of these has an elevation of 4,650 feet, the second of 4,625 feet, and the two southern ones each an elevation of 4,700 feet. From the crests of these peaks, as from the edge of the tableland, one looks toward the east into two immense basins, called respectively the North basin (see plates 33 and 34), lying at the base of the North peaks, and the South basin (see plates 32 and 35). For a considerable distance the South basin is inclosed between the walls of the tableland; but at its southern side rise the highest peaks of the mountain, commonly called the South peaks (East and West peak on plate 31), which reach an elevation of 5,150 feet, or 860 feet above the tableland, whose elevation is 4,290 feet. From the high South peak there extends as the southern wall of the South basin the exceedingly narrow and rugged ridge already described, which reaches the last remaining peak of Ktaadn, Pamola, whose elevation is 4,760 feet.

So far as the mountain top is concerned, it consists, therefore, of a broad area of rather level land and a number of peaks with moderate slopes. What the conditions are on the southwestern and western sides of Ktaadn I can not say in detail, not having examined that region carefully; but toward the east there is some striking topography. From Pamola, past the South peak and as far as the North peak, a distance of several miles, the eastern and southern walls of the mountain are everywhere precipitous and in places inaccessible. This precipitous wall is interrupted by a spur from one of the North peaks, which, together with the spur of Pamola, incloses the broad South basin (see plate 30), while to the north of the spur is the smaller North basin.

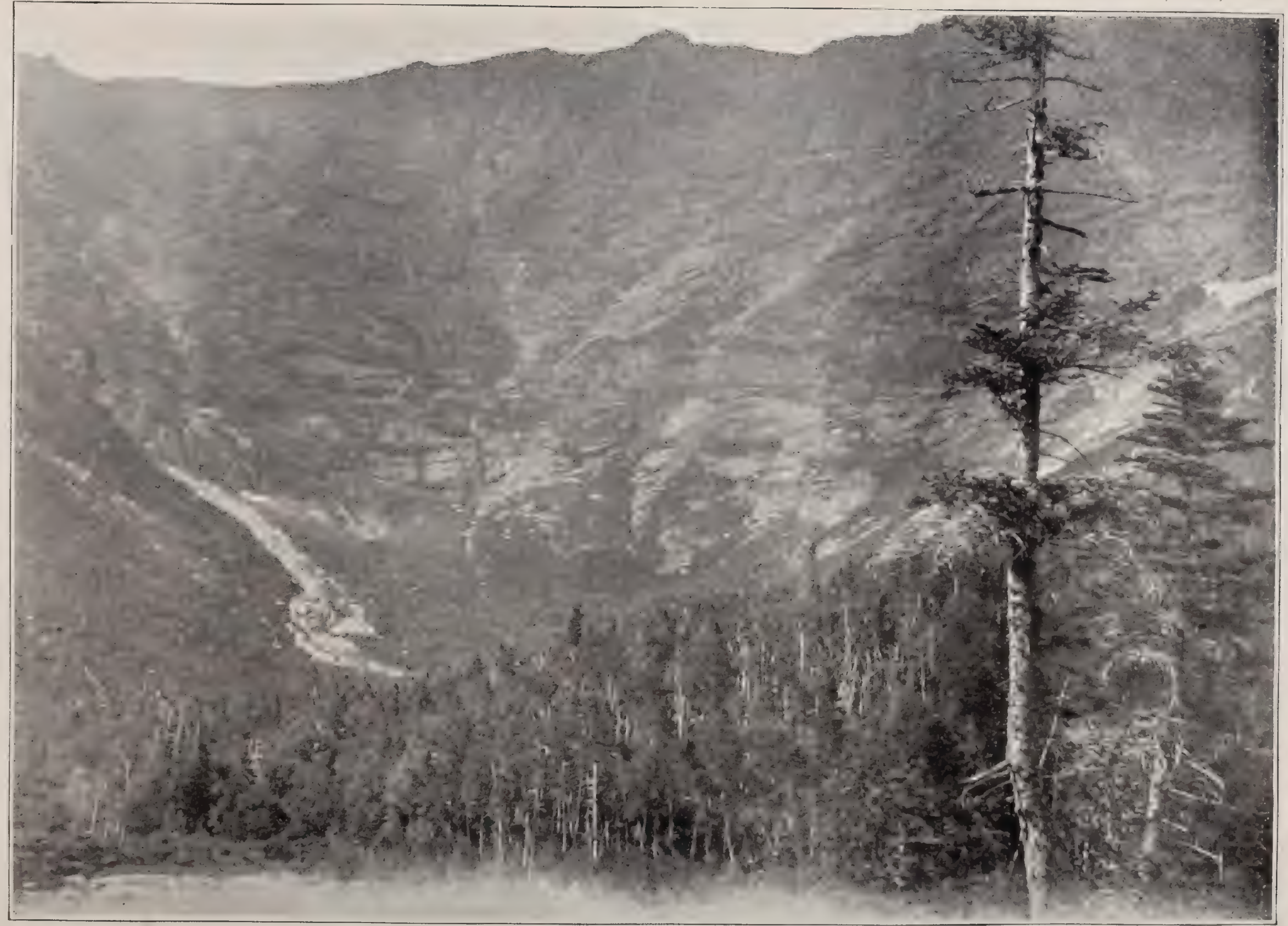
Concerning these basins Hamlin writes as follows:

> "The Great basin (the South basin), in its whole extent, forms an amphitheater, which, seen from above, strongly resembles an old volcanic crater. In the absence of trigonometrical measurements, its dimensions cannot be accurately stated; but they may be approximately given as from summit to summit east and west two and a half miles, by a mile and a half from north to south. Its most precipitous part, the southern lobe, measures from its head to the Basin Pond about three-fourths of a mile, and its width is nearly the same. The smaller North Basin approaches in shape the capital letter U, and is about a mile and a half long and half as wide, fronting a little south of east. The larger basin has a narrow gateway opening to the northeast."



SOUTH BASIN, MOUNT KTAADN

View is taken looking up the basin. Pamola is on the extreme left



SOUTH BASIN, MOUNT KTAADN

View taken from Central ridge—an avalanche on the left

In both the South and North basins, and also below their entrance, are a number of lakes, whose location is shown on the accompanying model (see plate 31). As one looks down from any part of the wall of either the South or North basin, his eye rests on an irregular floor, which has every appearance of being a moraine (see plates 32 and 39), and which is dotted with numerous small lakes, ponds, and swamps.

EVIDENCE OF VALLEY GLACIERS

In preface to this section it is well to call attention to the present climatic conditions of Ktaadn. Throughout the winter the mountain is deeply snow-covered, and the winds whirl vast quantities of snow into the basins. So deep is the snowdrift that in both the North and South basins large snow banks still remained on June 27 (see plate 33), and seemed liable to remain for a week or two longer. In September the snow commences to fall again, and in fact snow squalls occur throughout the summer. It snowed while our party was on the mountain, on June 26. A very slight change in the climate, through increased elevation or decrease in the mean annual temperature, would bring about conditions of glaciation on Ktaadn at present.

That valley glaciers have descended from the tableland and from the various peaks into the South and North basins no one will question who has seen the evidence, which is very clear and of different kinds. In the first place, the remarkable smoothness of the precipitous rock walls (see plates 34 and 35) is evidence that they have been only recently exposed to the weather. The difference in appearance between these slopes and the same rocks upon the mountain top is very noticeable. They are so precipitous that extensive avalanches (see plate 34) frequently occur, several having fallen within the last few years. Moreover, the walls are exposed to vigorous frost action, to heavy water action, and to fierce winds; yet the amount of weathering since they were exposed to the air has been exceedingly slight. While no glacial scratches were detected and no polishing that was evidently due to ice action, the very smoothness of the walls and the minute development of talus at the base of the cliffs are striking evidences that the walls have not long been open to the air.

The resemblance between the steep, smooth walls of these basins and the sides of certain valleys in the Nugsuak peninsula of Greenland, from which the glaciers are just now leaving, attracted my attention at once. In that portion of Greenland there are places from which the glaciers have almost entirely withdrawn, leaving in their place either entirely stagnant snow patches, which protect the rock from the frost, or else almost stagnant hanging glaciers, which scarcely deserve the name glacier. This close resemblance suggested to me that the walls of the South and North basins were just recovering from the blanket of snow which is the immediate successor of the dying valley glacier.

A second and more definite class of evidence of valley glaciers is the moraine deposit. This is very much more clearly shown in the North than in the South basin, because of the absence of trees in the former. The entire basin away from the inclosing walls is occupied by a distinct hummocky moraine (see plate 35), with kettles, in at least two of which there are ponds. This moraine is strewn with boulders, nearly all of which are of the Ktaadn granite, the number of foreign fragments being exceedingly limited. The resemblance between this moraine and that of Dogtown Common, Cape Ann, Massachusetts,* is very striking.

There is also a well defined lateral moraine upon the southern side, where it stands as a bench against the granite wall of the basin, above which the bare rock of the mountain is clearly seen. This lateral moraine merges into what appears to be a medial moraine, extending into the forest and joining with a lateral moraine from the South basin. The denseness of the stunted tree growth at this place, and the difficulty of travel through it made it impossible to determine the nature of this ridge with certainty; but its position and form suggest a medial moraine, and its association with other evidences of valley glaciers was such as to make this determination almost certain. Upon the north side of the North basin the lateral moraine is not well defined within the basin proper, although a distinct ridge is traceable from near the mouth of the basin out into the forest. Although very high, almost too high for such a moraine, this does not appear to be a rock ridge, nor is it in line with the undoubted rock ridges of the basin. I should not wish to pronounce it positively a lateral moraine, though I fail to see any other explanation for it.

In the South basin the tree-cover prevented the clear recognition of moraines in a part of the basin; but enough could be seen to prove that it has an irregular, hummocky floor, largely composed of boulders of Ktaadn granite.

Near the basin entrance, just below the Basin pond, which is in one of the kettles, there is a "dry pond," in which the evidence of moraine form is clearly shown (plate 36). The low hills inclosing this dry pond are rugged, and, so far as the surface shows, composed almost entirely of boulders (see plate 37), so that traveling over it is exceedingly difficult, some of the boulders attaining a very large size. The "dry pond" is a kettle in the midst of these boulder-covered hills, and that its bed is

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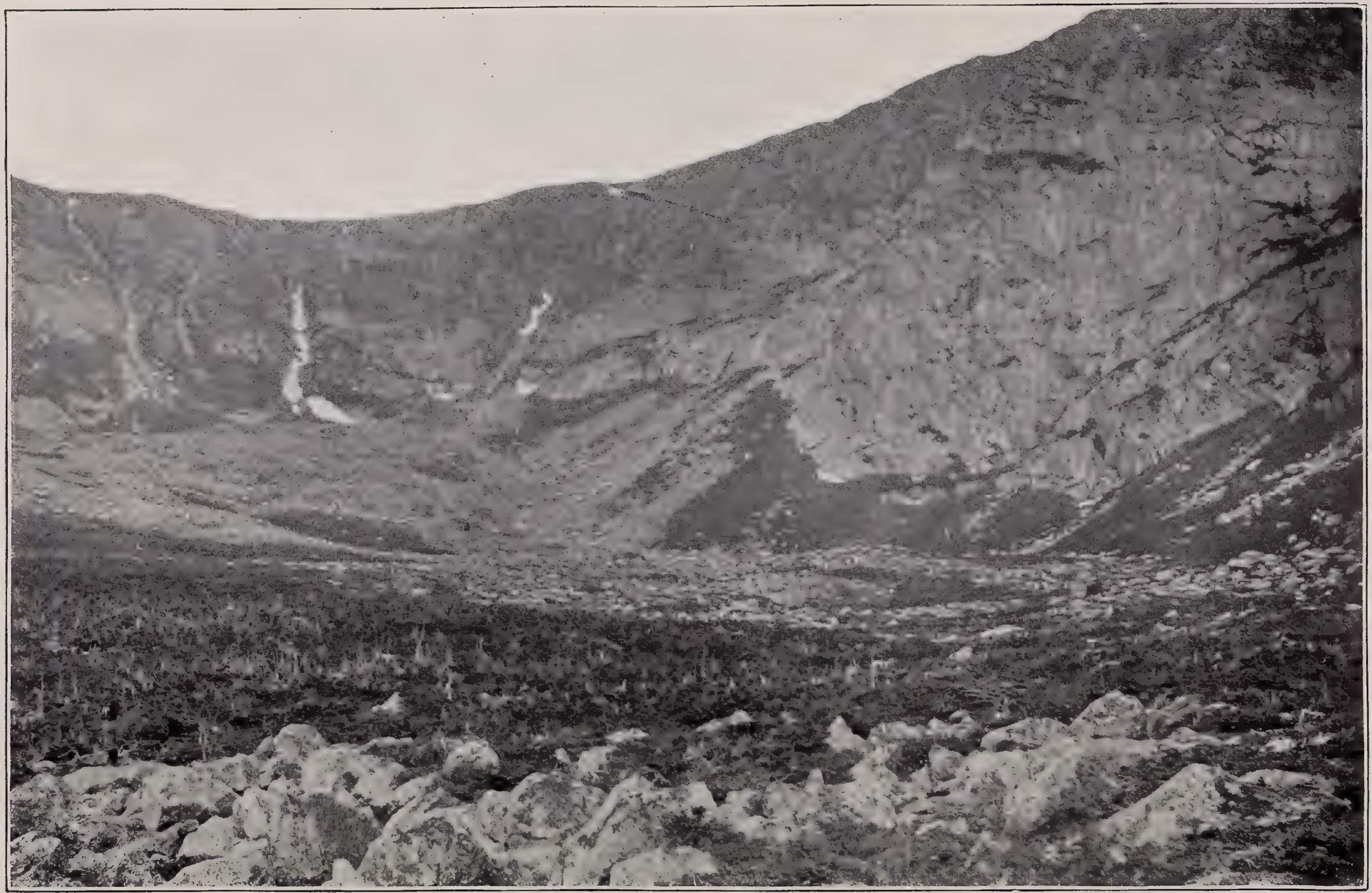
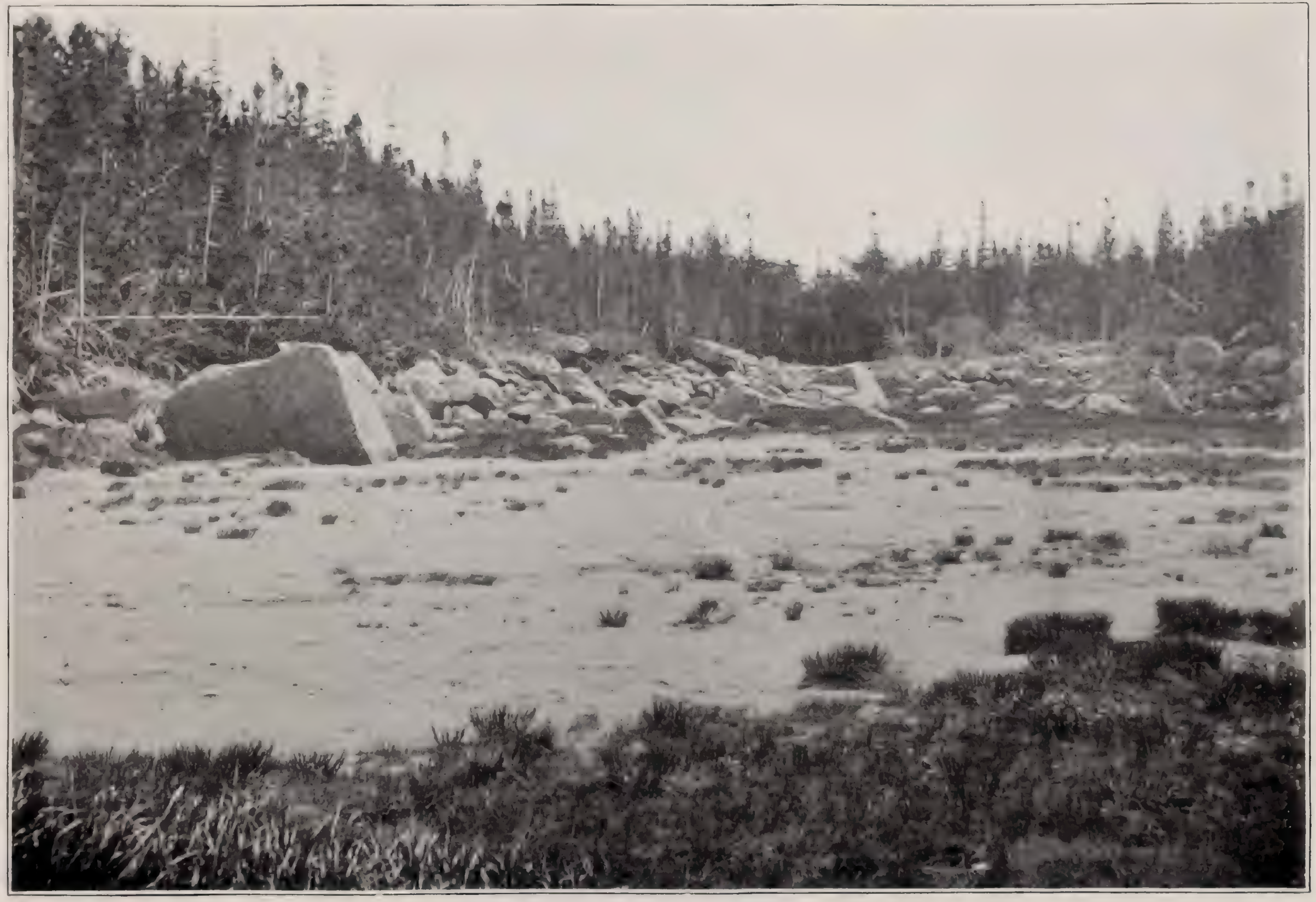
*See Shaler: Ninth Annual Report U. S. Geol. Survey, p. 546; Tarr: Amer. Jour. Sci., vol. cxliii, 1892, p. 141.



NORTH BASIN, MOUNT KTAADN

View taken looking up the basin and showing the hummocky moraine floor



SAND FLOOR OF "DRY POND"

Occupying a kettle in the Bear-den moraine, plate 37 also made of similar boulder accumulations is proved by the fact that, even when the stream draining the South basin reaches as far as the "dry pond," the water generally sinks through the sand and entirely disappears. The only time when there is water in this "dry pond" is during the spring freshets. There is evidently an accumulation of loose boulders here into which the water sinks as it might into the pores of a sponge. Even above this pond the same condition is proved to exist by the fact that after every heavy rain the brook advances toward the "dry pond" and then quickly disappears. Our camp was located at the junction of the brook with the "dry pond," with a plentiful supply of water on the first night; but each day it was necessary to go farther and farther up the stream for our water supply.

One possible explanation of ridges of drift with a large percentage of local material is that of crag and tail; but the form and position of these ridges disprove that explanation. It might be suggested that these boulder accumulations (see plate 37) are ancient avalanches; but this is impossible, for they are too far away from the cliffs; and, moreover, there are similar moraines a mile farther from the mountain than these. As has been stated, the boulders of both moraines are mainly of Ktaadn granite, which of itself is evidence of local rather than general glaciation. Very few foreign fragments, and those of small size, were found in a careful search among the boulders. Moreover, many of the fragments, especially in the basins, are remarkably fresh, as if recently brought to their present position.

Beyond the entrance to these basins hummocky deposits still continue, and although the region is forest-covered and exceedingly difficult to examine, it requires but a few sections across the country to find evidence of the morainic nature of the deposits; but even without this, there is a chain of ponds, extending at right angles to the axes of the basins and at a distance of a mile or two from their mouths, which are evidently located behind a dam of terminal moraine (see plate 38) formed by the union of two glaciers, one from the North basin, the other from the South basin. This chain of ponds consists of three rather large ones (see plate 39), which Hamlin has located on his map (see plate 31), and two others which he has not placed there.

The morainic wall which incloses the ponds is almost impossible to examine in detail, for it is covered with a low, tangled brush of spruce and birch (the "pucker brush" of the Maine woods), through which it is impossible to push one's way, under which one can not go, leaving but one remaining means of travel—to pass over it. It was brush of this kind, and in this region, on which Thoreau says that he walked for some distance, actually traveling on the tops of the stunted trees.

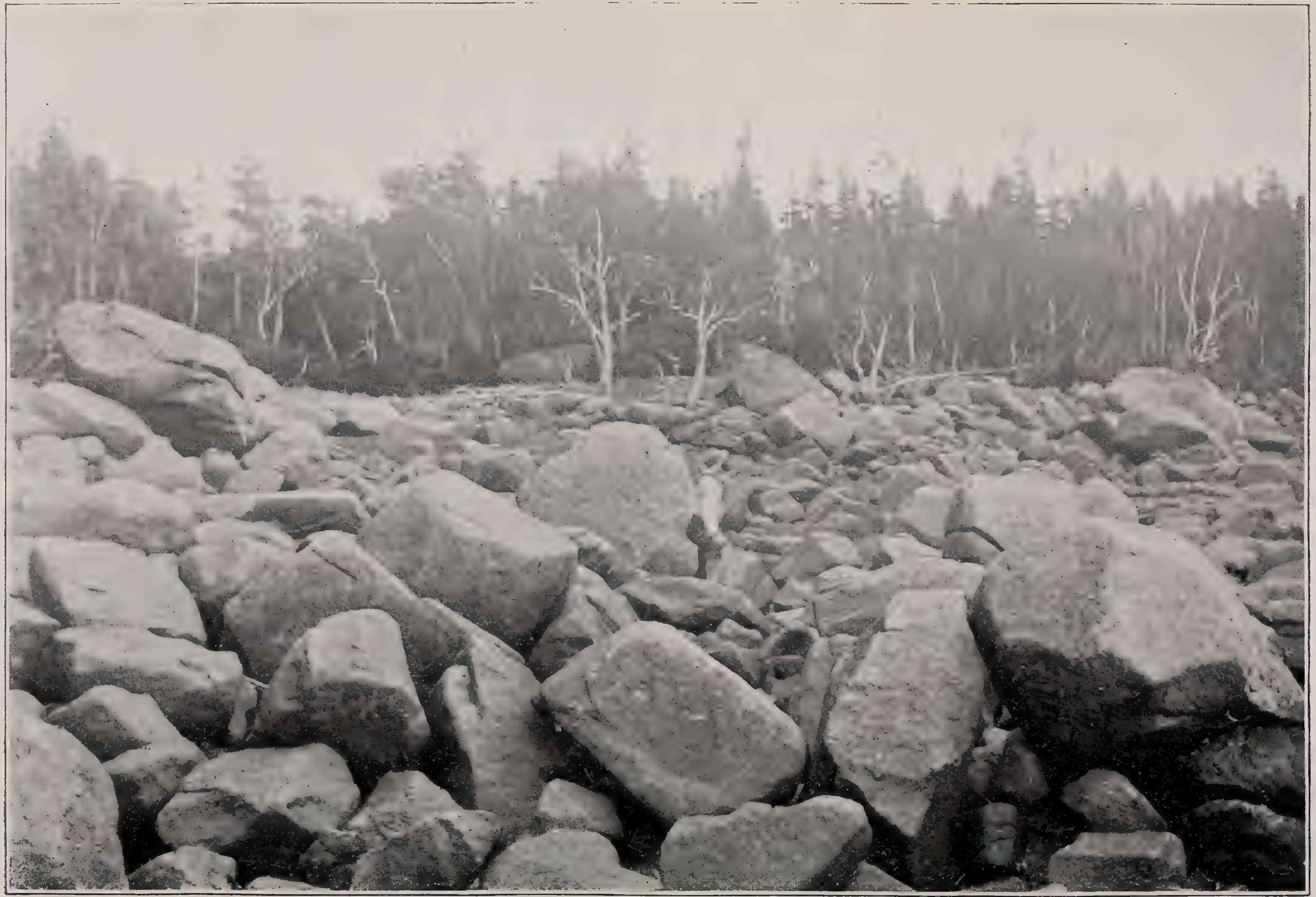
Two or three attempts to penetrate this tangle were sufficiently successful to prove the nature of the deposit. It is properly located for a moraine, and is hummocky, with numerous small kettles. It is remarkably high, and the two longer ponds, whose beds are boulder-strewn, have a depth of certainly more than 25 feet, while the moraine which incloses them rises from 15 to 60 feet higher than the surface of the ponds (see plate 38). On the side away from the basins the height is much greater than this.

This high ridge is classified as a terminal moraine. It extends in front of the mouths of two distinctly preglacial valleys, so that it seems impossible for it to be a rock ridge, for such a ridge, in such a position, would have been out of harmony with all known laws of stream erosion. Not only its position, but its form and composition, indicate that it is a dam of debris derived from the union of the two glaciers from the North and South basins, possibly with the addition of a small glacier from the side of Pamola, for it projects farther from the mountain opposite the place where the South basin and Pamola glaciers would have united. Hamlin's model shows the location of this ridge very well.

Possible existence of other Glaciers

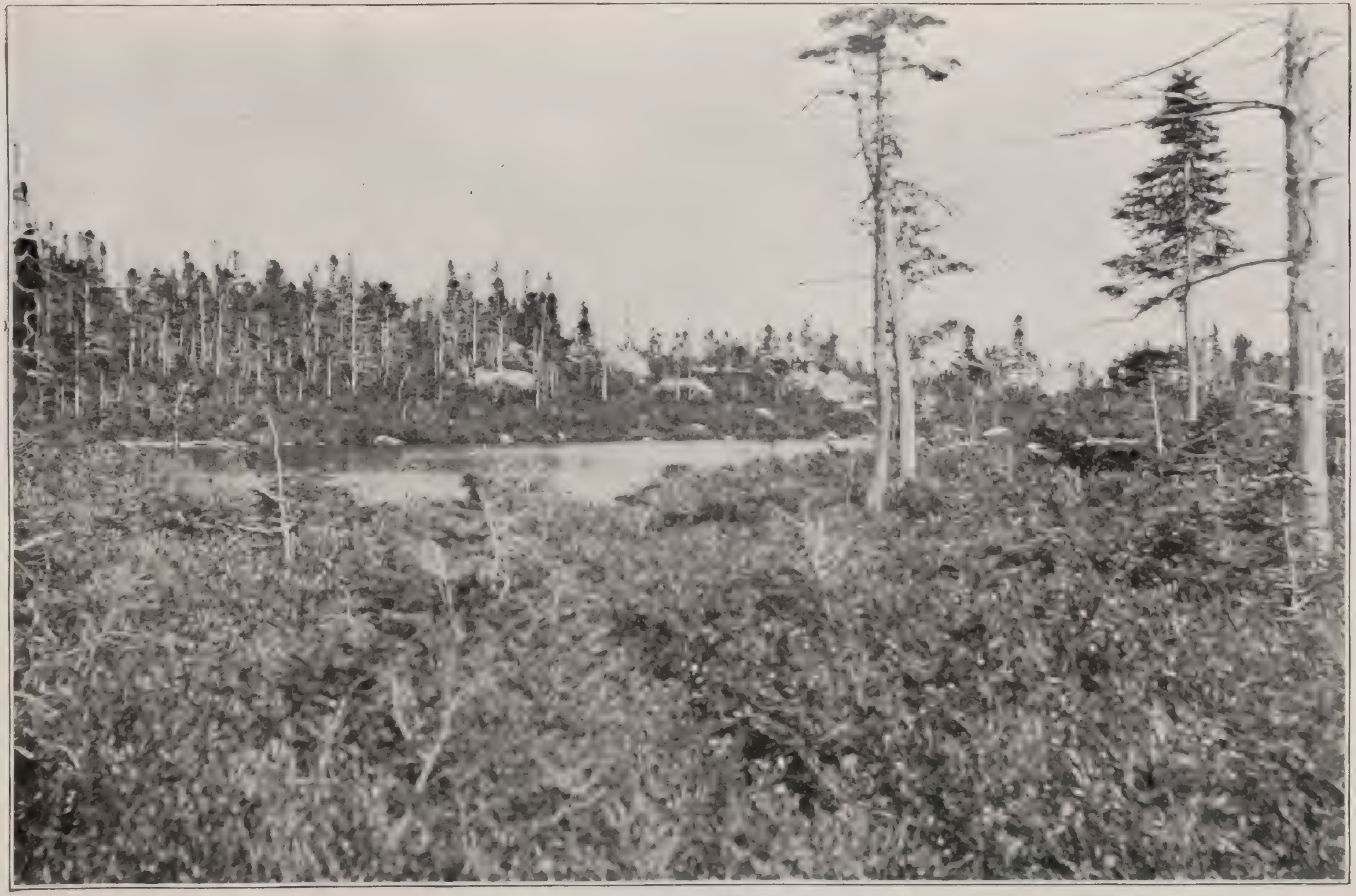
Near Ktaadn are a number of other high mountains. The nearest of these is Turner mountain, which is separated from Ktaadn by a moderately broad valley. While no distinct evidence was obtained concerning valley glaciers from this mountain, the presence of lakes near it and their position indicate the possibility of valley glaciers having descended from this mountain also. From casual observation the same suggestion occurs concerning Traveller mountain and the group of mountains to the northwest of Ktaadn. In fact the great abundance of small ponds in the neighborhood of Ktaadn leads to the question whether a number of valley glaciers from separate centers have not united and together extended to a considerable distance from the mountain, building morainic dams for such lakes as Ktaadn lake. This is no more than a mere suggestion as to the direction toward which future work might be extended.

There seem also to have been valley glaciers extending in other directions from Ktaadn. A suggestion of one of these is found at the Russell ponds, which lie just to the north of the north spur of the mountain; but sufficient work was not done in that region to make it absolutely certain that these moraines were formed by the valley tongues from the mountain, although all observations indicated this.



BEAR-DEN MORAINE, MOUNT KTAADN

At the "dry pond" on the Basin trail



ONE OF THE MORAINE-DAMMED PONDS

Forming a chain opposite the entrance to the South and North basins—moraine ridge in background

Hitchcock* has suggested that during the time when the Saint Lawrence valley was depressed to a considerable depth below the present level, local glaciers from several different centers invaded that bay, and that, since this was during the last stages of the glacial period, it is the evidence from this source which has led the Canadian geologists to the view that a Canadian ice-sheet has not invaded the New England states. I wish to bring this forward as a rational working hypothesis, even though I have no facts to add to it at the present time. The principal reason for bringing it forward at this time is my conviction that such an event is to be expected as one of the closing episodes of the ice invasion. Some evidence in support of the belief in such a condition of ice movement has already been presented by the Canadian geologists.

Indeed it seems that this hypothesis would, if proved, harmonize the conflicting views of the American and Canadian schools of glacial geologists. There is in New England a sufficient amount of highland to carry snow fields of large size, from which glaciers might radiate in all directions, much as we now find in portions of Greenland, and as has been so clearly proved to have been the condition in the British isles. There is good reason for believing that the Greenland glacier formerly advanced over Disco island; but now, the great ice-sheet having withdrawn from it, the highland of that island forms a separate center of glaciation. The glaciers from this center of distribution are now shrinking and have in the past been much more extensive than at present. The normal conditions of ice advance and retreat, as I conceive them, would first of all cause local centers of distribution, then general glaciation, which would last until, finally, the highest glaciers had dwindled down to mere snow banks, which themselves would at last disappear. This conception, applied to Maine, is more fully stated in the section which follows.

A Conception of the Glacial Period in Maine

With the coming of the glacial conditions, the loftier New England mountains, being subjected to the conditions of cold, must have accumulated snow fields and sent out valley glacier tongues which coalesced with others. The conditions of glaciation increased until, from large centers, extensive sheets of ice moved outward in all directions, much as the British geologists have proved to have been the condition among the highland centers of the British isles. With the onward march of the ice-sheets from the different centers, there was a coalescing, first of the smaller, then of the larger masses, until at last the union of the glaciers from the highlands of the United States with those of Canada produced one large ice-cap, which advanced over New England even to the sea. This continental ice-sheet, rising higher and higher on the mountain sides, finally enveloped even the loftiest and steepest peaks.

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*Bull. Geol. Soc. Am., vol. 7, 1896, pp. 3, 4.

Of this earlier set of local glaciers no evidence has been found, and it is doubtful if much exists; for, with the activity of later ice erosion, that of the continental glacier and the succeeding local glaciers, the signs of the primary local glaciers would have been in large part, if not completely, erased. Concerning the advance of the ice of the great continental glacier, until it overtopped even the highest mountains, sufficient evidence has been brought forward, as was stated in the first part of this paper.

The period of continental glaciation in New England must have been of considerable duration, for there is everywhere distinct evidence of ice-scouring on the mountains which projected into the ice-sheet. This is so pronounced as to constitute a prominent element in the topography of Maine. It was noticed by Thoreau, and has been mentioned by many other writers, that the northern slopes of the hills and mountains are often moderate, while the southern slopes are steep. In some cases this is evidently due to structural peculiarities in the rock-masses forming the mountains; but elsewhere it is entirely independent of this, and no other explanation than ice-scouring seems rational.

One who has studied this aspect of the action of the Greenland continental glacier is prepared for just such a modification of topography. For instance, in the mount Schurman nunatak* the ice has passed up the stoss slope and scoured and smoothed it perceptibly, while the west, or lee, slope is a precipice against which the ice is doing almost no work. The various mountains along the Greenland coast again and again illustrate the same characteristic of form, even when entirely outside the limit of present ice erosion. This is noticeably the case in the mountain called the "Devil's Thumb" on the Ryder map.† In Maine instances of this are so numerous as not to need specific mention. They are seen on all hands, and are often so evidently out of relation to rock structure as to seem to demand the explanation of glacial erosion.

Following the long stage of continental glaciation, there came a shrinking of the ice. Then some of the New England peaks, such as Ktaadn and Washington, rose so high that they projected above the surface as nunataks, reaching higher and higher above the ice-sheet, as the glacier melted, until a sufficient area of country was exposed to permit the accumulation of snow fields, with valley glaciers descending from the mountain tops. With the withdrawal of the great ice-sheet there again

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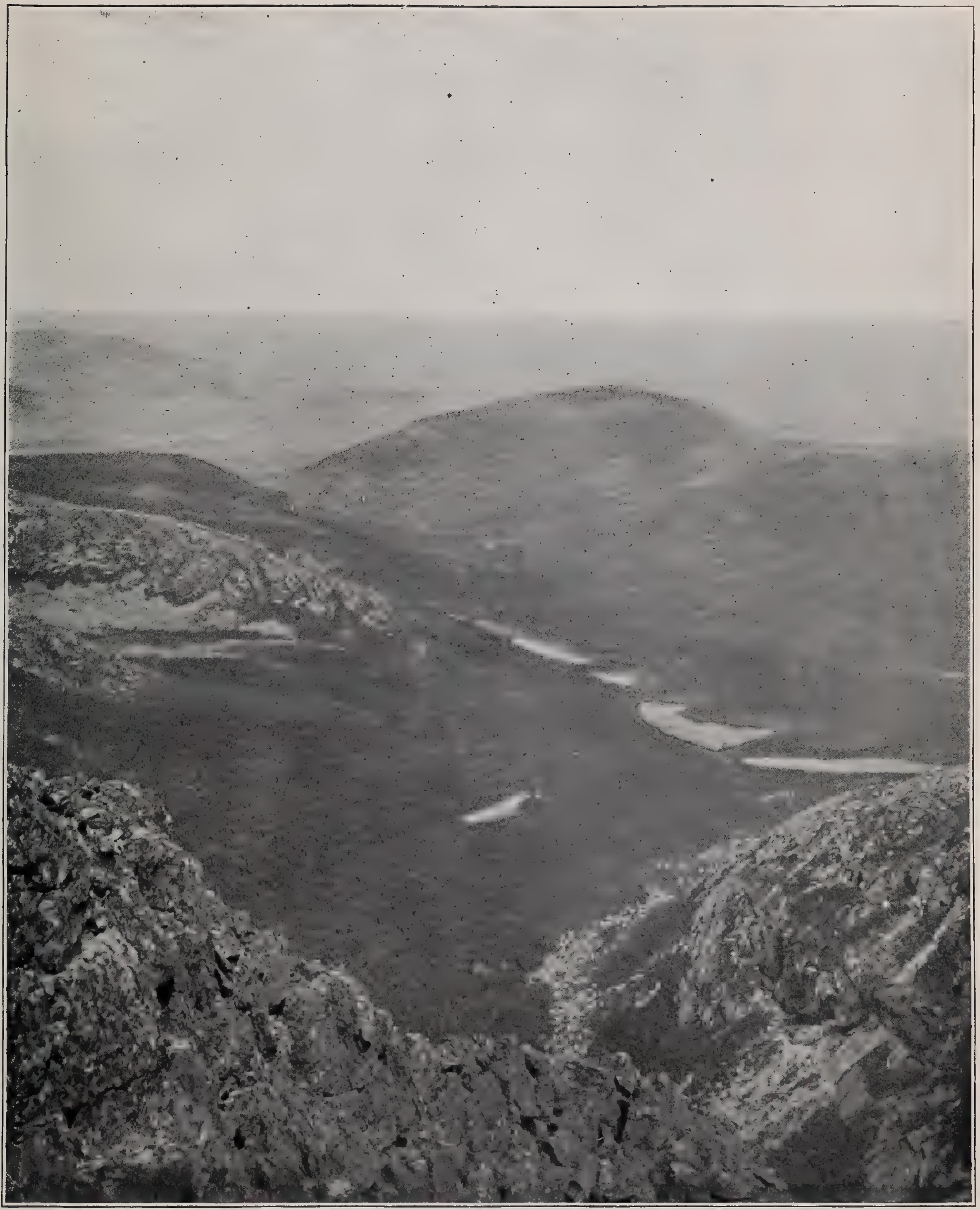
* Tarr: Amer. Geologist, vol. xx, 1897, p. 147.

† Bull. Geol. Soc. Am., vol. 8, 1897, p. 254.



THE MORAINIC PONDS

As seen from the slopes of Mount Ktaadn

came a period of local glaciation, which at first may have been from several centers—as, for instance, from the Adirondack center, the Green Mountain center, the White Mountain center, and the Ktaadn center—with glaciers sufficiently extensive to reach well into the Saint Lawrence basin, perhaps discharging icebergs, with their rock load, into the enlarged bay of Saint Lawrence. The continued shrinkage of these large centers gave rise to coalescing valley glaciers, which were finally replaced by isolated, unconnected glaciers, such as those which occupied the North and South basins of Ktaadn.

This last stage certainly existed in the Ktaadn region, and from the writings of others seems proved for the White mountains and elsewhere in New England. Therefore, of this assumed history, some of the stages are inferred, while others may be considered proved; and that part which is inference is strengthened by the fact that this order of events is that which seems to have been followed in other similar regions.

There is an admirable opportunity for further study of the glacial geology of the northern Maine region, for in that region lies the key to an understanding of some of the important events of the Glacial Period in America. It will be by no means an easy study to make, since, aside from the difficulties of traveling due to the forest cover, and from the countless millions of insect pests which inhabit the forest, there is an almost universal absence of cuts in the glacial deposits and an almost complete burial of the bed rock. One may travel through the forest for scores of miles without finding a rock outcrop; for, even when present, the forest mould, moss, and fallen trunks conceal it from view almost as completely as a soil cover would. Where the rock itself outcrops it has been exposed to the weather so long that signs of glacial action have been almost completely destroyed. The chance for study will be found mainly in tracing the distribution of blocks of rock from the mountain centers. Until that has been done the full history of this region can not be written.

Summary

Mount Ktaadn is a granite mountain in northern Maine. It reaches to an elevation of almost a mile above sealevel. Previous observers have reported that the highest peak of the mountain bears no proof of ice covering, and it has been inferred that it rose above the ice as a nunatak. It is one of the objects of this paper to present evidence that the ice did overtop Ktaadn.

A second point of the paper is to show that, as a last stage of ice-action, valley glaciers occupied the valleys on the east side of Ktaadn, building well defined moraines, some of which inclose lakes.

The proposition is made, as an hypothesis, following the suggestion of Hitchcock, that between the time of general glaciation and local valley glaciers, there was a stage during which from the various highland centers of New England glaciers reached northward into the Saint Lawrence valley. This would account for the features described by the Canadian geologists and harmonize the conflicting views of the Canadian and American glacialists.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 11, PP. 449-454, PL. 40 JUNE 22, 1900

VERTEBRATE FOOTPRINTS ON CARBONIFEROUS SHALES OF PLAINVILLE, MASSACHUSETTS

BY J. B. WOODWORTH

(*Presented before the Society December 30, 1899*)

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GEOLOGY OF THE AREA

CONDITION OF STRATA AND FOSSILS

The footprints described in this paper were found in the northwestern corner of the Narragansett basin after a report on this region by Messrs Shaler and Foerste and the writer had gone to press.* In this report it is brought out that a small part of the Narragansett basin is not more metamorphosed than the Paleozoic rocks of the New York state system, and that in this tract the conditions for the preservation of fossils are peculiarly good. In the region to the south and east the Carboniferous strata have been folded, and particularly toward the south metamorphosed to such an extent that the organic contents of the beds have been largely distorted beyond recognition or actually effaced.

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*Monograph xxxiii, U. S. Geological Survey, Washington, 1899. Footprints noticed in postscript on page 98.

DISTRIBUTION OF METAMORPHISM

The contrast between the Wrentham area and the remainder of the basin is very great in regard to the metamorphism of the rocks. This is largely due to the intrusion of pegmatites in successively greater pipes and dikes as we proceed southward from the vicinity of Providence toward the mouth of Narragansett bay. In the Wrentham-Attleboro area igneous action has been limited to the intrusion of dikes of diabase, and to the intrusion and effusion of masses of felsites and granophyric rocks which have exerted little or no influence on the strata. Such changes of texture as have been observed in the northwestern corner of the basin are clearly ascribable to lateral pressure, which is manifested in the crushing of sediments in closed folds. Where blocks of strata have escaped this action the beds remain without cleavage and without the development of new minerals.

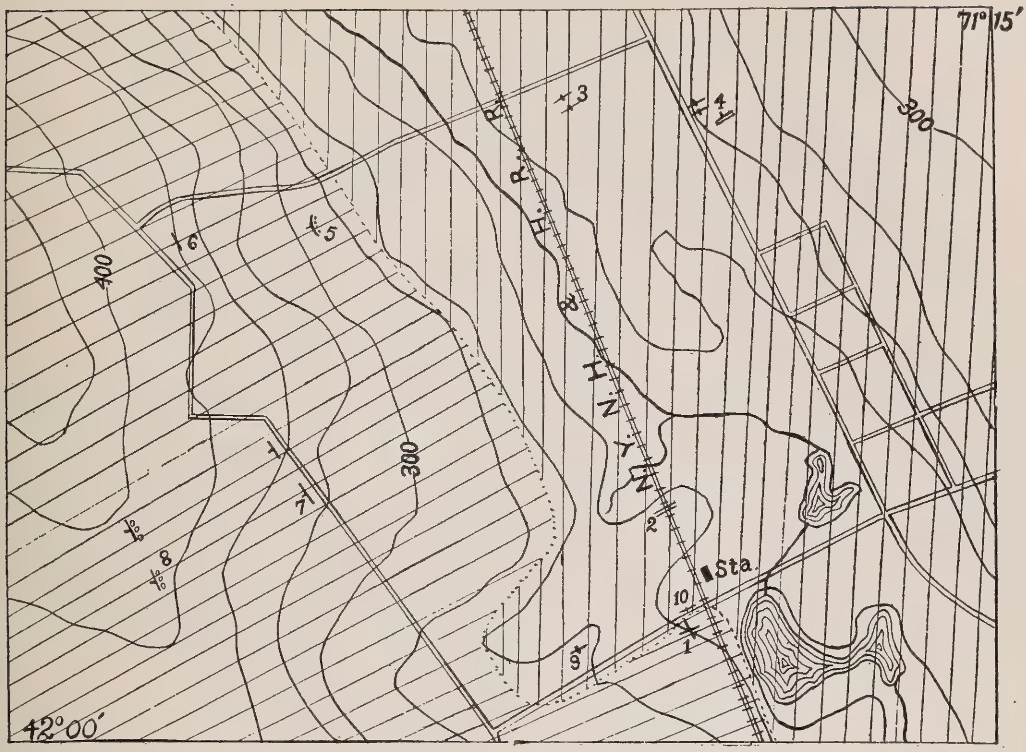
STRUCTURE OF THE WRENTHAM-ATTLEBORO AREA

The structure of the area in which fossils have been found is one of combined folding, faulting, and overthrusting in which the sequence has been folding with overthrusting, followed by faulting. About an inlier of pre-Carboniferous granitite with Lower Cambrian beds lying near the northwestern corner of the basin is wrapped a highly folded series of locally lower Carboniferous beds with igneous associates in the form of a horseshoe-shaped area open on the north. Between the arms of this structure on the north of the pre-Carboniferous mass or core lies an overthrust and downfaulted block of locally middle Carboniferous strata tilted westward. The strata on which this block rests are vertical beds of Carboniferous equally high in the series and closely beset with cleavage. In the overlying block are found the fossils here described.

Geology of Plainville

DISTRIBUTION AND CHARACTER OF THE STRATA

The accompanying sketch map of the vicinity of Plainville, in the southern part of the town of Wrentham, is intended to illustrate the general features of the fossiliferous locality. The strata consist of an alternation of gray feldspathic sandstones and shales, with occasional massive ndurated mud beds, and one known bed of coal.



▨ Blake Hill fault-block, with southwestward dipping Carboniferous beds, uncleaved, unmetamorphosed.

▥ Vertical beds of Carboniferous series in Plainville valley and the ridge east of the town, slaty in structure.

Figure 1.—*Geologic Map of the Vicinity of Plainville, Massachusetts.*

1. Footprint locality, shales overlain by gray sandstone, much jointed, dipping gently southward.
2. Vertical shales, sandstones, and grits.
3. Two parallel vertical ledges of alternating slates and slaty sandstones.
4. Highly inclined curved ledges of sandstones and slates.
5. Quarry, sandstones with shaly layers, varying westerly dips; raindrop imprints, Asterophyllites.
6. Shales and sandy shales, gentle southwest dip; raindrop imprints.
7. Southwestward dipping ledge, traceable to the southeast, conglomerates, sandstones, and shales.
8. Strong ridge of conglomerates and sandstone, with shale layers.
9. Vertical slates, with gray sandstones.
10. Vertical slates.

Dotted line shows approximate trace of thrust-plane along which the vertical beds disappear beneath the fault-block.

BLAKE HILL FAULT-BLOCK

This block of strata forms the western wall of Plainville valley, the floor of which is composed of the vertical Carboniferous beds shown on the map, figure 1. The trace of the thrust-plane on the surface is clearly indicated by the distribution of outcrops. The footprints occur in shales at the bottom of the block west of the Plainville railroad station and on the south side of the street at the locality marked number 1 on the map.

On the opposite side of the street occurs an outcrop of the vertical slate series standing at a higher level than the nearly flat beds exposed 30 feet distant. The sandstones of the base of the block are very thickly beset with joints as the result of the overthrusting of the block.

Westward on that margin of the block beyond the limits of the sketch map the gray Carboniferous rocks of the block abut against red beds belonging near the base of the Carboniferous series, the relation being effected by faulting.

RAINPRINT HORIZONS

At several horizons on the eastern face of the Blake Hill fault-block the shales have been observed to carry the impressions of rainprints, showing that the mud beds were bared to the air, and that the entire series was accumulated in shallow water if not in a fluvial or lacustrine plain. This geographic feature suggested the search for the footprints of Carboniferous amphibians—a search which was at once successful.

FOOTPRINTS

DESCRIPTION OF THE PLAINVILLE TRACKS

The footprints represent the tracks of two individuals, one set being small and distinct, the other larger, but indicated by two imperfect impressions only (see plate 40, figures 1 and 2).

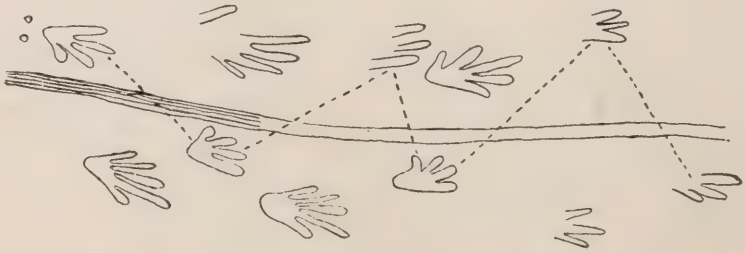


FIGURE 2.—*Batrachichnus plainvillensis* sp. nov. ($\frac{1}{1}$).

The smaller tracks are those of a four-footed, tailed animal (see figure 2), with fairly distinct impressions of fore and hind feet. The fore feet gave four-toed, the hind feet five-toed, impressions. The following measurements are given to supplement the illustrations :

Fore foot : length, 6.5 millimeters ; breadth, 4 millimeters.
Hind foot : length, 11 millimeters ; breadth, 5 millimeters.
Length of stride, left manus, 22 millimeters.
Breadth of tail-groove, 1.5 millimeters.
Breadth of track, 22 millimeters.

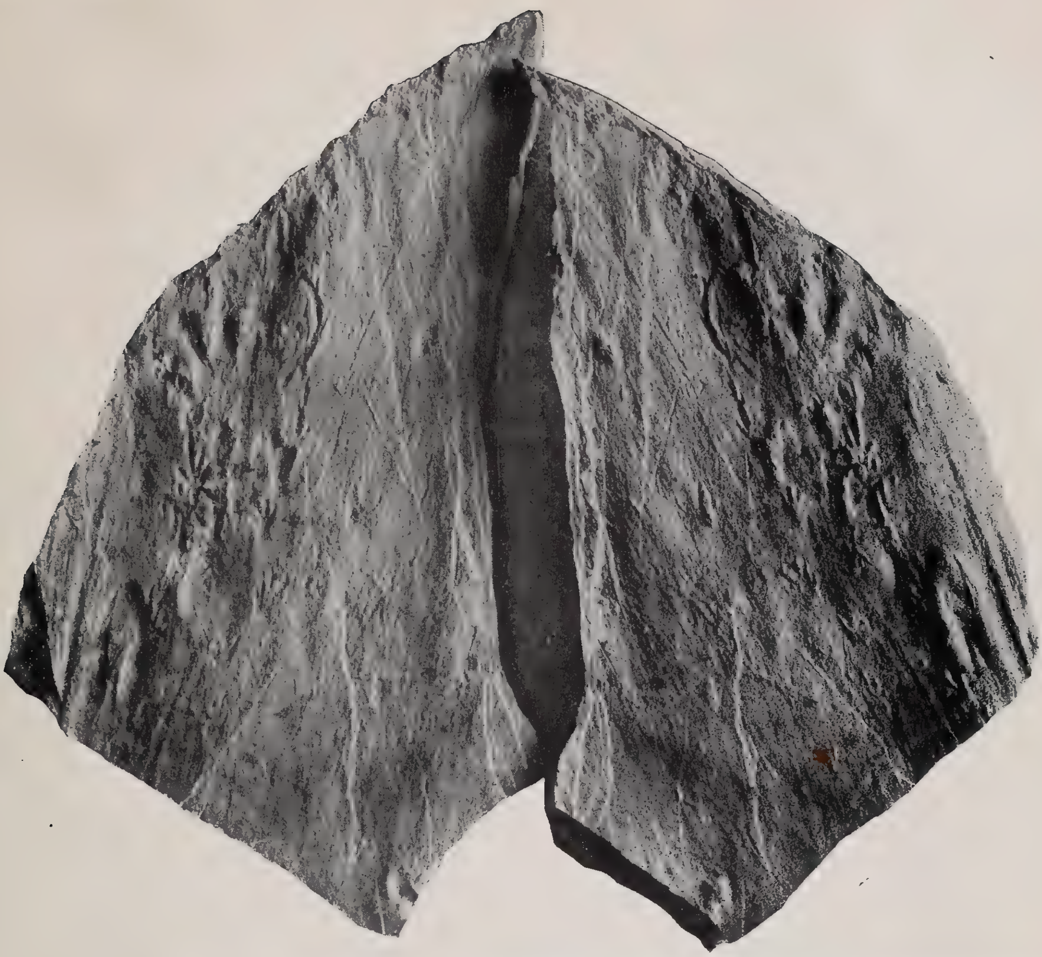


Figure 1.—Reproduction of Footprints of *Batrachichnus plainvillensis*, sp. nov. from Plainville, Massachusetts

Left-hand fragment of shale shows original impressions. Right-hand fragment is a mold cast in the succeeding shale layer. Parts of two large footprints can be seen at extreme right and left of fragments.

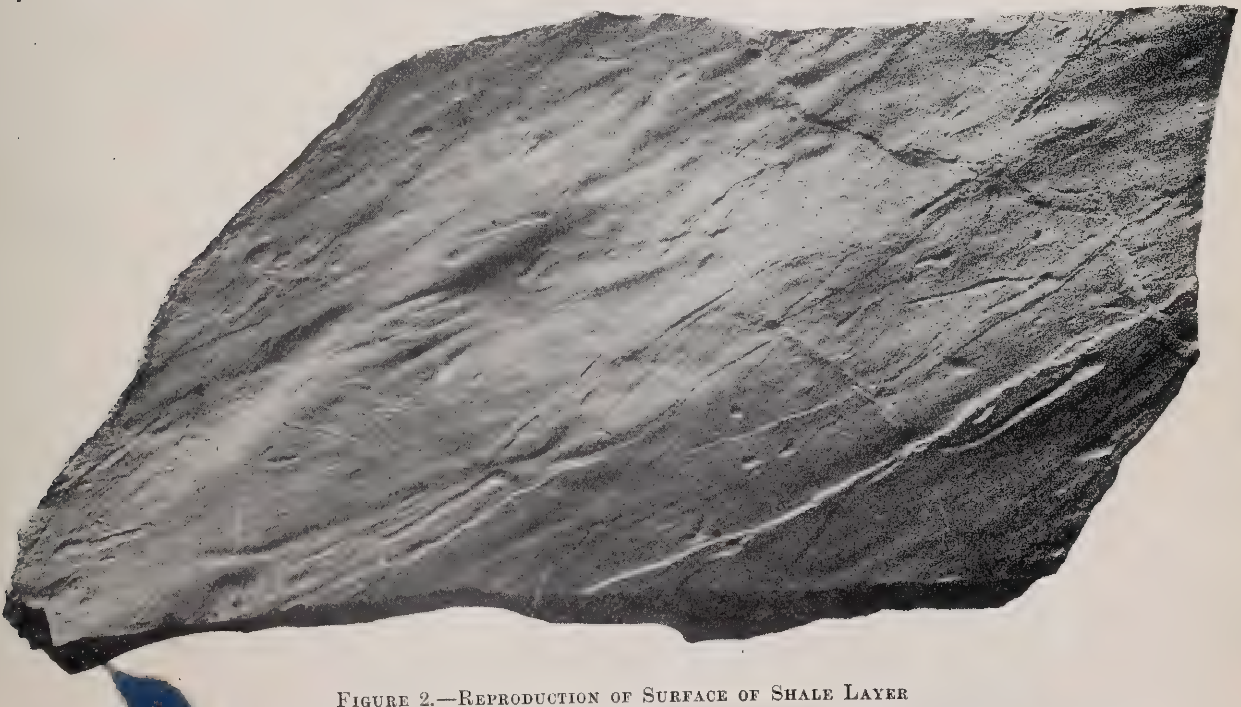


Figure 2.—Reproduction of Surface of Shale Layer

Showing scratches and imprints attributed to amphibia touching mud bottom in act of swimming or crawling. Locality 10, Plainville, Massachusetts

AMPHIBIAN FOOTPRINTS

A comparison of the tracks with existing newts and salamanders and with the known amphibia of the Carboniferous and Permian serves to establish an identification with the Stegocephs such as the Amphibamus described by Cope * from the Carboniferous of Ohio. A form having the size and shape of Melanerpeton of the Permian of Germany described by Fritsch † might have made the tracks and the tail-groove. A salamandroid feature will be noted in the inward toeing of the fore foot and outward pointing of the hind foot. Following the practice of Fritsch and Marsh, the name *Batrachichnus* is here given to these tracks, with the specific *plainvillensis* in allusion to the locality of their discovery.

The two large footprints seen on the same slab (plate 40, figure 1) are clearly distinct from the small tracks and show more of the characters of Cheirotherium, in this respect resembling tracks found in the Nova Scotia Carboniferous. These and other obscure prints of even larger size in the Plainville district are too imperfectly known at present to deserve further mention here.

DISTRIBUTION OF FOOTPRINTS IN EASTERN CARBONIFEROUS AREAS

The finding of these newt-like tracks in the Narragansett basin now completes the tracing of these amphibians of the Carboniferous throughout the remaining areas of the Carboniferous mud-flats of northeastern America, except for some local basins in which it is probable that the rocks are too much altered for the identification of delicate imprints.

The moist and cool habitats of the existing land forms of the present period is entirely consonant with the theory of Croll that the later Carboniferous was a time characterized by a lowering of the temperature over the lands of widely separated areas. This local refrigeration of climate was probably in part due to elevation of the land. The extreme to which Carboniferous climate was carried by this or other causes is evident from the glacial records of India and Australasia. The faculty of withstanding a period of freezing, as shown by Dufoy, explains in part the persistence of the amphibian type from the Carboniferous to the present day.

CONDITIONS UNDER WHICH FOOTPRINTS WERE MADE

M. Stanislas Meunier has claimed, on the basis of certain experiments in the artificial production of buried footprints, that the fossil impressions have been made upon a water-covered surface, and that where overlain by sands this cover has been deposited by the action of winds blowing sand and dust over the area of deposition. The shales at Plainville offer an opportunity for an investigation of the circumstances under which they were made, and I find nothing to support the idea that the cover was not deposited in the same manner as the foundation on which these prints were made. In both cases the rock is consolidated mud. That the footprints may have been made beneath a slight depth of water seems highly probable for the reason that some parts of the tracked surfaces are marked with scratches (see plate 40, figure 2) such as would be made by the toes or nails of a small newt in lightly touching the bottom in swimming. If such light impressions can be preserved under water, of course the stronger imprints of the foot may not only be made, but preserved.

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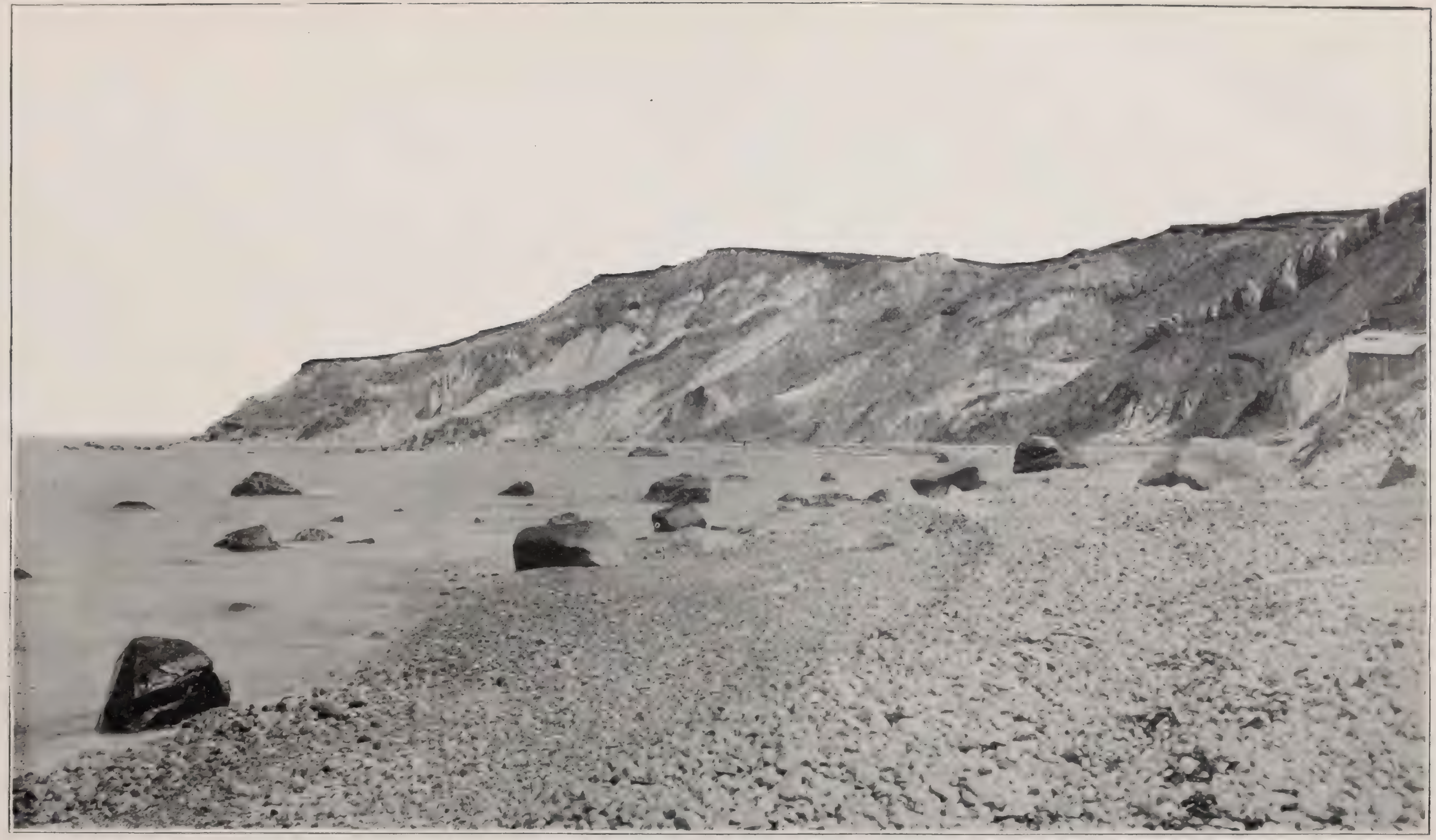
* E. D. Cope: Proc. Acad. Nat. Sci. Phila., 1865.

† Anton Fritsch; Der Fauna der Gaskohle.



GAY HEAD CLIFFS, LOOKING EAST FROM BEACH

Showing the general northeast dip of the folded and overthrust strata. From Gardner collection of geological photographs, Harvard University, number 2035. Photographed by Philip Sharples in 1894.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 11, PP. 455-460, PLS. 41-42 JUNE 22, 1900

GLACIAL ORIGIN OF OLDER PLEISTOCENE IN GAY HEAD CLIFFS, WITH NOTE ON FOSSIL HORSE OF THAT SECTION

BY J. B. WOODWORTH

(*Read before the Society December 28, 1899*)

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CONCLUSIONS DERIVED FROM PREVIOUS STUDIES OF GAY HEAD CLIFFS

In volume 8 of the Bulletin of the Society the writer described some of the characters of a boulder bed in the Gay Head cliffs and gave reasons for believing it to form the base of the Pleistocene deposits of the New England islands, at the same time pointing out its correlation with the Columbia of McGee.* In an earlier paper by Professor Shaler † a section was presented in which the geological position and distribution of this bed were indicated. The possible transportation of the fragments in this bed by some form of ice action was implied, but beyond the size of the boulders found in it, no direct evidence of glacial agencies had been discovered until April of this year. As the glacial origin of the deposit and its geological position have an important bearing on the extension of the first ice invasion to New England, the facts are here stated.

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* Bull. Geol. Soc. Am., vol. 8, pp. 197–212.
† Bull. Geol. Soc. Am., vol. 1, 1889, pl. 9.

Contents of the Deposit

The significant fact in the contents of the boulder-bed is the occurrence in it of large and small fragments of rock borne from known terranes constituting the mainland on the north. A small boulder of peridotite very clearly traveled from Iron Mine hill, in Cumberland, Rhode Island, a distance of 59 miles, approximately along lines of transportation of drift in the last ice invasion, though farther to the east than any fragments of this rock seen by the writer in the till of the last ice-sheet. Boulders of granite, gneiss, and diorite are present from the region about Westport, Massachusetts. Some of these fragments are angular. One boulder has already been described as having an approximate weight of 8 tons.

In addition to these materials which have been carried to and deposited on this disturbed section of coastal plain formations, the boulder bed contains fragments of the strata in the old coast plain, showing that the agency or agencies of transportation were capable of eroding materials quite down to the end of the journey—a feature possessed only by ice moving over the land or the shallow deposits of the sea. Floating ice could hardly have effected the transportation of blocks from Cumberland, at an elevation of 400 feet above the present sealevel, and also from the edge of the coast plain as it then existed, for one or the other of these areas would have been above or below the zone of inclosing debris for flotation, unless it be admitted that the land has been uplifted with reference to the two localities by a tilt as great as 10 feet to the mile, of which there is no evidence whatever.

Structure of the Deposit

The larger patches of the boulder bed exhibit an arrangement of the pebbles and cobbles which is indicative of water action. The smaller patches of larger boulders are less clearly stratified, and one patch, except for the absence of fine materials, might well be termed till. The frequently angular blocks of rock found in the deposits, particularly near the base, show that water action was feeble, or of short duration if strong. The same conclusion must be drawn from the occurrence of glaciated pebbles yet to be described. The pell-mell order of certain portions of the boulder bed can not be much relied on, for the reason

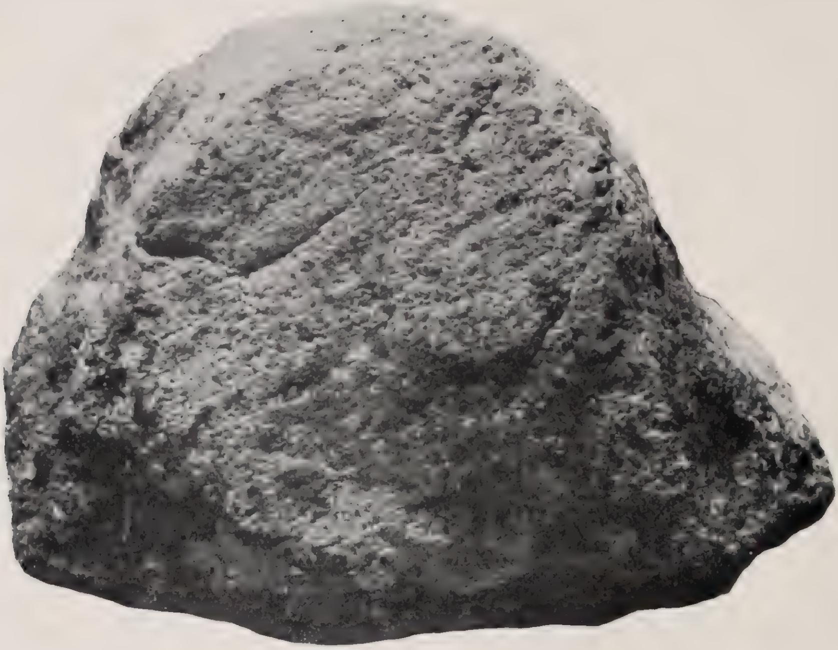

FIGURE 1.—GLACIATED PEBBLE OF HORNBLENDIC GRANITITE

Taken from basal boulder bed of the older Pleistocene (Columbia) in Gay Head cliffs. Locality 3100, of section in plate 9, volume 1, of this Bulletin

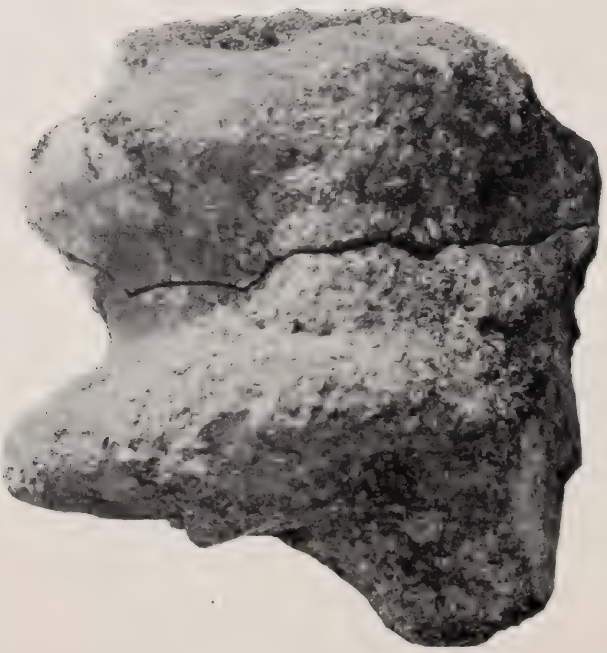

FIGURE 2.—PARTIAL VIEW OF INFERIOR SURFACE OF ASTRAGALUS OF FOSSIL HORSE

Taken from the Miocene osseous conglomerate bed at Gay Head, Massachusetts

GLACIATED PEBBLE AND FOSSIL HORSE BONE

that the beds have been involved in the Gay Head diastrophe, and such disorder may as well be due to internal movements of the section as to original deposition.

Glaciated Pebbles in the Deposit

In April, 1899, the writer began a search in the boulder bed for glacial pebbles, and found three specimens which are unmistakably glaciated. Two of these were hornblendic granitite; the third was diorite. The smaller of the granite pebbles is shown in plate 42, figure 1. The flattened side or sole, the snubbed ends, and the striæ are alike indications of the glacial abrasion of this pebble. The striæ, though faint, are better defined than on many glacial pebbles of that rock in the granitic area about Boston.

It can not be successfully contended that these pebbles are due to mud-flows or to talus-sliding, for their position precludes that. Neither are they due to solution in the bed after deposition, for quartz and feldspar grains alike are scored and grooved. Solution would have proceeded at unequal rates on these minerals and would have pitted the surface. The objection that the pebbles were scratched by coast ice and not by land ice is met by the peculiar distribution of the deposits with regard to the derivation of the materials from the coast plain and the New England extension of the Piedmont, from localities now at sea-level to those having an elevation of at least 400 feet above the present sealevel, in the manner above stated.

Relation of Deposits to the Subterrane

Undoubtedly an ice-sheet advancing on the coast plain as it must have existed along the southern shore of New England before the glacial period would have produced some disturbance in the deep soft rock section of which it was composed. Erosion by ice and water action would have taken place here and there on the disturbed and undisturbed sections alike. As pointed out in my paper before the Society in 1896, these boulder deposits everywhere rest unconformably by erosion on the Cretaceous or Miocene beds of the Gay Head section, and in one part of the cliff the Cretaceous beds stand vertically beneath the boulder bed. The local folding of the soft clays and sandy clays and the erosion, followed by the deposition of the boulders, may be considered as sequential parts of the advent of the first ice-sheet along this shore. The great overturning of strata at Gay Head and elsewhere on Marthas

Vineyard and Block island and, as I believe, as well on Long island took place later, but yet a very long time before the last ice advance.

Correlation of Deposits with Columbia Formation

That the boulder bed at Gay Head, together with the overlying gravels and sands, represents the lower part of McGee's Columbia formation follows by the definition of that term as regards the stratigraphic position and lithological character of the materials at Gay Head. The conclusion that the boulder bed represents the deposits of the first advance upon the Atlantic coast plain is also strictly in line with the understood origin of the Columbia. In the easternmost of these New England islands the Columbia is fossiliferous and is separated from later deposits, also of Columbia age, by the Gay Head diastrophe and unconformity dependent thereon. This lower Columbia was termed the Sankaty in my paper of 1896.

Interpretation of Columbia Epoch

It has been shown by McGee that the Columbia was a time of submergence to a depth of at least 400 feet south of New York. There is nothing to disprove this submergence during Sankaty time in the New England islands or on the neighboring mainland. On the contrary, a depression to this depth would account for many bodies of glacial clays which occupy embayments along the shore, as in Boston basin, and which were deposited anterior to the last ice advance in this region.

After several years of repeated visits to the Marthas Vineyard sections and a visit to the island of Moen, in the Baltic, the writer is unable to find any direct evidence in either of these fields proving conclusively that the upturning of the beds has been brought about by glacial thrust. It is perfectly clear that the folding and displacements took place after the first invasion of ice in both fields and before the last; hence clearly within the glacial epoch. Without committing oneself to the verity of the hypothesis of glacial thrust, some conclusions may be drawn from Gay Head as to the mode of action of the supposed ice-thrusts. When we compare the folding accomplished just before the deposition of the boulder bed with that which took place later, we note that the two are as one to ten in volume of beds displaced. On the supposition of displacement by ice-thrust, the relative exemption of the coast plain from disturbance during this first advance may be explained by the submergence of the region, so that the ice rested lightly on the surface, whereas in the later glacial advance it bore directly on the soft terrane of Cretaceous and Tertiary strata, and so displaced the mass to a great depth and over a broad tract.

NOTE ON GAY HEAD FOSSIL HORSE

OCCURRENCE IN OTHER LOCALITIES

The bones of the prehistoric American horses have been reported from the Atlantic slope in beds of Pleistocene age in New Jersey and from the Pliocene of Florida. I have been unable to find that bones of this animal have been encountered in the coast plain strata in the north. The finding of a single fragment at Gay Head in the osseous conglomerate bed is therefore of some interest.

THE OSSEOUS CONGLOMERATE

The osseous conglomerate of Hitchcock [*] is a mixture of water worn, white vein quartz and chert pebbles with mammalian bones, sharks' teeth and vertebræ, as well as occasional fragments of lignite and silicified wood. The mammalian bones heretofore reported have all been marine types, the bones of whales and a walrus,[†] this latter form being based upon a skull found on the cliffs, but thought to have come from the bed. The age of the bed has been by several competent authorities determined as Miocene.[‡]

ASTRAGALUS OF HORSE FROM OSSEOUS CONGLOMERATE

The evidence of a fossil horse in this section is based on a fragment of the astragalus of the left hind limb found by the writer in May, 1899. This bone is shown on plate 42, figure 2. The bone was broken in extracting it from the bed, and there can be no doubt about its occurrence as a constituent of the osseous conglomerate. The matrix adhering to the specimen is that characteristic of that formation. The determination of its equine nature depends on the identification of Professor Osborn, of Columbia, who kindly examined it for the writer.

PROFESSOR OSBORN'S OPINION ON AGE OF THE HORSE

Professor Osborn finds that the type of astragalus is more like that of the known Pleistocene horse, though it was found in beds of recognized

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[*] Edw. H. Hitchcock: Final Report on the Geology of Massachusetts, 1841, p. 424.

[†] Chas. Lyell: Travels in North America, vol. 1, New York, 1845, pp. 203–206, pl. v.

[‡] W. H. Dall: American Journal of Science, vol. xlviii, 1894, pp. 296–300.

Miocene age. A similar difference of opinion has existed in the southern field with regard to the age of beds containing a mammalian fauna, with *Equus fraternus.* It would seem that the osseous conglomerate of Marthas Vineyard needs further study by our paleontologists.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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THOMSONITE, MESOLITE, AND CHABAZITE FROM GOLDEN, COLORADO

BY HORACE B. PATTON

(Read before the Society December 30, 1899)

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WORK OF PREVIOUS INVESTIGATORS

The zeolites of North and South Table mountains at Golden, Colorado, have already become known to mineralogists mainly through the excellent descriptions of these minerals and of their occurrence by Cross and Hillebrand in Bulletin 20 of the United States Gelogical Survey.* In this bulletin the above named authors † have given a brief description of the Table mountains, with their basaltic caps and a much more detailed description of the various zeolitic minerals contained in the amygdaloidal cavities. They also discuss the results of the investigations of Professor Carl Klein on the optical anomalies of analcite and apophyllite from this locality.*

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*Contributions to the Mineralogy of the Rocky Mountains, Bull. no. 20, U. S. Geol. Survey.

† A briefer, preliminary paper by the same authors was published in Am. Jour. Sci., 3d ser., vol. xxiii, 1882, p. 452, and 3d ser., vol. xxiv, 1882, p. 129.

During the past two years the Colorado State School of Mines, located at Golden, has been conducting quarrying operations for the purpose of securing for its mineral cabinet specimens of these Table Mountain zeolites. A new locality opened up on the east face of North Table mountain proved to be very prolific of these zeolites and produced many specimens of extreme beauty.

In most respects the zeolites here developed correspond closely with the occurrences described in the above mentioned paper by Cross and Hillebrand, and it is hardly worth while to duplicate what they have already written on the subject. The minerals thomsonite and mesolite, however, not only show extraordinary beauty, but occur in a great variety of forms, habits, and associations, and in the case of the former also present features that do not entirely accord with the descriptions of Cross and Hillebrand.

Place and Mode of Occurrence

As the description of these zeolites and of the Table mountains in which they occur are so readily accessible to all, a very brief reference to the surroundings will suffice for our present purpose. At Golden are two socalled table mountains, designated North Table mountaih and South Table mountain. Geologically they are but one mountain, consisting of soft, nearly horizontal beds of Middle Tertiary age, capped with a thick lava sheet and cut in two by Clear creek. The soft bedded rocks that form the base of the mountain are almost entirely composed of fine andesite ash beds belonging to the Denver Tertiary.† The lava cap consists of two flows of feldspar-basalt that together reach a thickness of about 100 feet at the place where the minerals under discussion were obtained. The second flow followed so closely upon the first that no erosion of the first sheet occurred before it was covered by the second sheet. The two flows are of about equal thickness and form a nearly vertical cliff of 100 feet, in the center of which is a horizontal band of very scoriaceous basalt that belongs mainly to the top of the lower flow. This porous band is some 15 feet thick and contains cavities of all sizes up to 6 or 8 feet. The large cavities are drawn out flat in the direction of flow; the smaller ones may be flattened oval in shape. Even in the weather-beaten face of the cliff the presence of white zeolitic minerals filling the cavities is very noticeable. At a depth of 2 or 3 feet they are usually quite fresh.

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* Neues Jahrbuch für Mineralogie, etc., vol. i, 1884, p. 250.

† See Whitman Cross: Geology of the Denver basin, Monograph xxvii, U. S. Geol. Survey, p. 155.

Cross and Hillebrand divide the zeolites filling the amygdaloidal cavities in the basalt of North and South Table mountains into two groups, based upon their method of occurrence. The minerals of the first group are laumontite and stilbite, and are to be found only on the floor of the cavities. On the floor of many of the cavities, especially of the larger ones, there is to be seen a very peculiar bedded deposit of yellowish or reddish yellow color, which closely resembles a friable sandstone, but which is shown to be composed of mixtures of these two minerals. Included in the minerals of the first group are also to be mentioned occasional minute, reddish spherules of thomsonite. These latter have not been observed by the writer in the newly opened locality; but with this exception the minerals of the first group are quite in accordance with the descriptions given by Cross and Hillebrand and may be passed over without further comment.

The second group is made to include all those that are not confined to the floor of the cavities. They occur on the roof and sides, as well as on the floor composed of zeolites of the first group, or they completely line cavities that do not contain these bedded floors. The minerals of this second group are thomsonite, stilbite, chabazite, analcite, apophyllite, and mesolite, to which may be added calcite and aragonite, as both these minerals occur associated with the zeolites of the second group.

Thomsonite

GENERAL DESCRIPTION

It is universally recognized that specimens of any given species coming from the same locality usually have the same habit and general appearance. This similarity affects crystal form and habit, color, luster, size, and association, and is so marked that mineralogists do not hesitate to identify localities by such peculiarities, such identification of localities usually being entirely justified by the facts. Exceptions to this rule will doubtless suggest themselves to the reader, but it is doubtful if a more striking one can be found than is shown by the mineral thomsonite in the particular locality under discussion. It would not be difficult to select four or more specimens of this mineral coming from immediately adjacent cavities so markedly different in habit and general appearance as to suggest their occurring in widely different localities. In fact, one may be justified in stating the contrast in still stronger terms, inasmuch as it is difficult to realize that the several specimens really represent the same mineral, irrespective of their common origin. This great diversity is undoubtedly due to the fact that the several varieties have been formed under varying conditions. It is, indeed, possible and easy to recognize several generations of thomsonite, each generation having its own habit. As a matter of fact, two such generations were recognized and described by Cross and Hillebrand. Their description of the first generation is very exact, and specimens of this type may easily be identified from such description. It is not so easy, however, to identify their second generation with any individuals of the later ones described in the following pages. Without the aid of photographs or other illustrations, it is no easy matter to convey an accurate conception of minerals whose forms are not clearly cut. It is to be hoped, therefore, that the reproductions of carefully made photographs accompanying this paper will give something like an accurate idea, impossible through the printed page alone, of the occurrences under discussion.

Altogether three distinct types may be distinguished, representing successively later generations. In at least two cases one or two subtypes are recognized and are designated by the letter *a*. It is not, however, always possible clearly to distinguish these subtypes, as they pass into each other by many intermediate stages. In case of the three main types, designated as I, II, and III, there is ordinarily no difficulty in making the proper distinction. This may be done by the peculiarities of development, as well as by the association with the other zeolites and with each other.

TYPE I

This represents the ordinary habit of thomsonite as it occurs in many places on both Table mountains, and is very characteristic of the locality. The following description of this habit, taken from the paper by Cross and Hillebrand, fits the occurrence admirably:

> "The mineral occurs in very minute rectangular blades, which are placed upon each other like the leaves of a closed fan, and the very compact combinations of such aggregates are usually arranged in a more or less distinct radiate manner. Sometimes spherical forms result, in other cases columns, by radiation from an axis, or, less frequently, walls, the blades standing at right angles to the central plane. . . . When a large surface of chabazite has been completely coated by the more or less radiate aggregates of thomsonite, forming an undulating surface, the whole has a most delicate silken luster, while that on a fractured surface of a spherical mass is more satin-like."

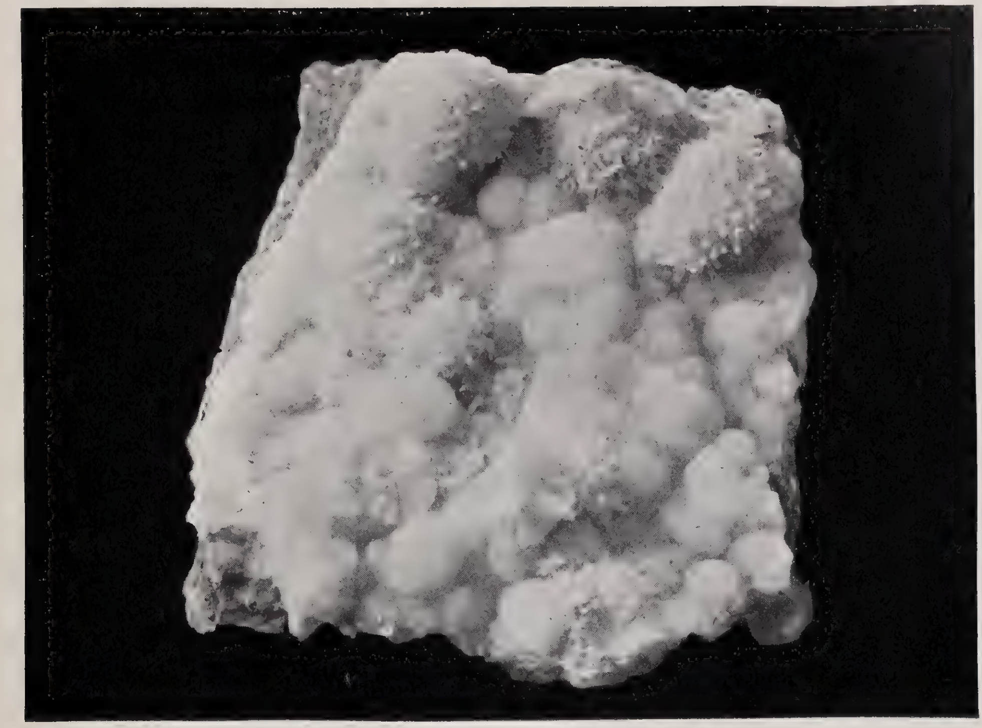

FIGURE 1.—THOMSONITE OF TYPE I

Partly covered by Thomsonite of Type III*a*. Chabazite underlies the whole. Two-thirds natural size

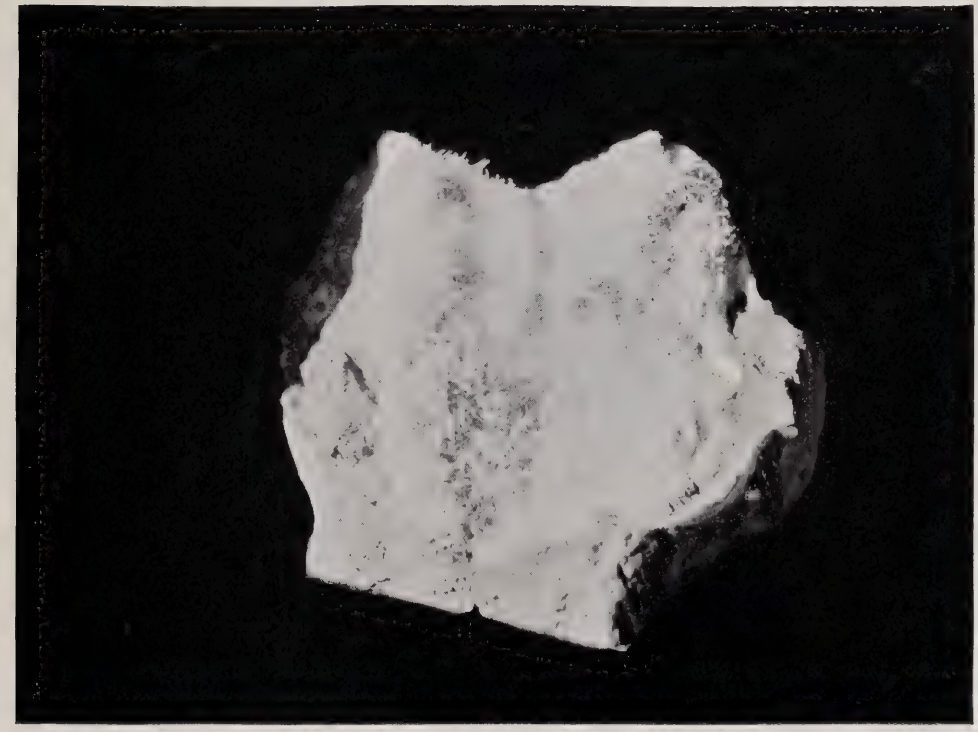

FIGURE 2.—THOMSONITE OF TYPE II

Underlain by Thomsonite of Type I. One-half natural size

THOMSONITE OF TYPES I AND II

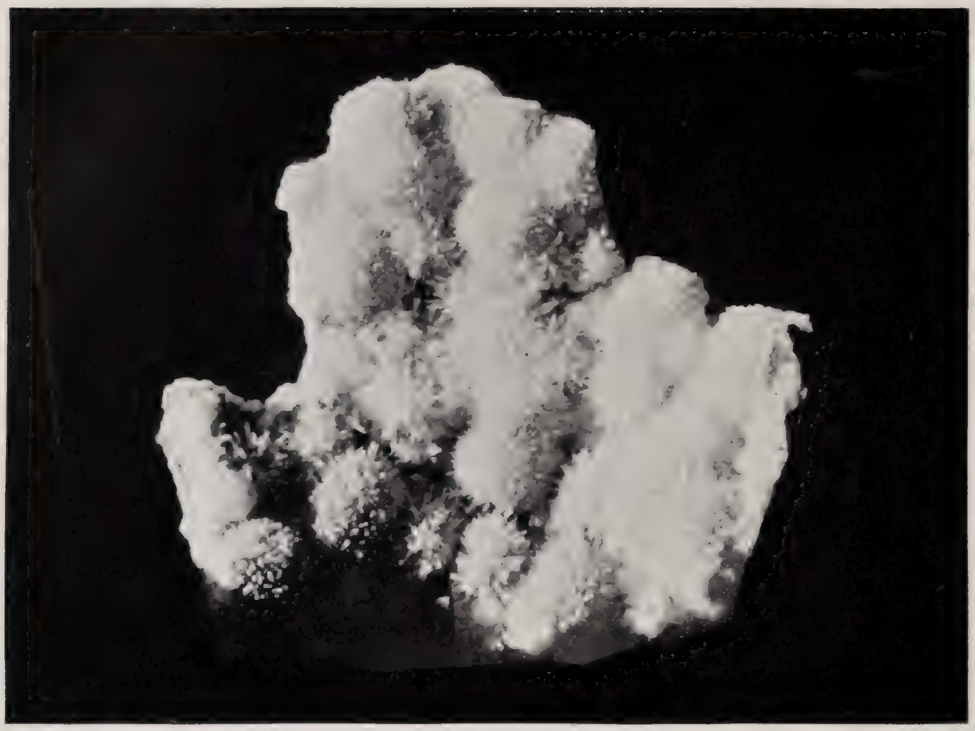

FIGURE 1.—THOMSONITE OF TYPE II*a*

Underlain by Thomsonite of Type I. One-half natural size

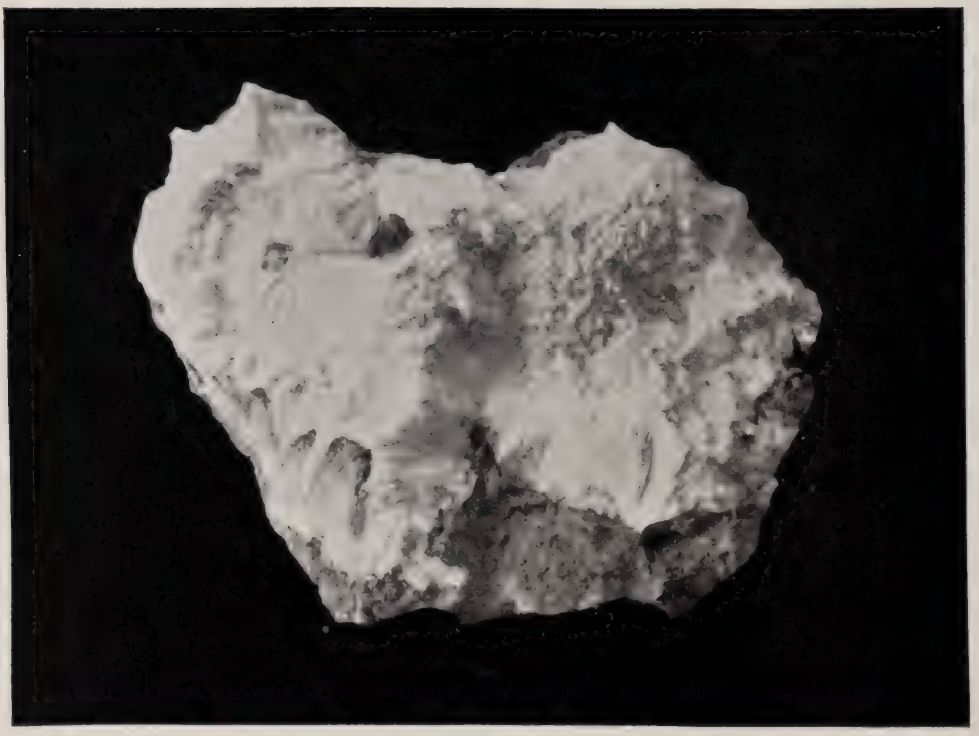

FIGURE 2.—THOMSONITE OF TYPE III

One-half natural size

THOMSONITE OF TYPES IIa AND III

Figure 1 of plate 43 gives an excellent idea of this habit. The globular appearance is very characteristic of many of the specimens. In the lower part of the figure may be seen two or three of the spherical aggregates broken open so as to show the radiated structure and the satin-like luster. In this specimen the surface of the cavity was first coated by a continuous thin layer of chabazite, which does not show in the figure. This, in turn, was completely covered by the thomsonite. A later generation of thomsonite, to be described under type III*a*, forms rough surfaced globular aggregates grown on the surface of the first generation.

In their description of the individual minute leaves that make up these radiate aggregates, Cross and Hillebrand refer to the macropinacoid as the dominant form with subordinate prism and brachypinacoid, the terminal face being the basal plane. As the prism is nearly at right angles and the leaves examined measure only about 0.01 millimeter in thickness, this determination is naturally only a surmise, based on the generally accepted forms given in the standard mineralogies. In spite of the minuteness of the constituent leaves, it is quite possible, however, by optical investigations to show that the brachypinacoid rather than the macropinacoid is the dominant form. This determination is based on the generally accepted fact that the best cleavage is parallel to the brachypinacoid, and the plane of the optical axes is parallel to the basal pinacoid, with the acute positive bisectrix parallel to the macro-axis. According to these accepted properties of thomsonite, one would expect to observe a positive bisectrix, with the axial plane at right angles to the vertical crystal axis on the best cleavage planes. These observations have been verified in numerous cases on individual leaves and on carefully selected cleavage pieces, as well as on random cleavages produced by pulverization. The mineral cleaves very easily parallel to the leaves and only indifferently at right angles to the same. This determination of the position of the positive acute bisectrix was also supported by the behavior of the same material in parallel polarized light. Individual leaves and cleavage pieces invariably show the axis of least elasticity parallel to the vertical axis. The extinction is always parallel. It should be stated, however, that when the cleavage pieces are not selected, but are obtained by pulverization and examined at random, occasionally one may lie on the poorer macropinacoidal cleavage plane. In this case the vertical axis is the axis of greatest elasticity. It may be well to state here in anticipation that in case of all the other types of thomsonite, wherever the forms are tabular, the brachypinacoid may be shown in the same way to be the dominant form.

Thomsonite of this habit is very likely to be the first mineral deposited on the roof and sides of the cavities, and, where there is no bedded floor composed of mixed zeolites, this is also true of the bottom of the cavities. Usually, however, it is laid down on a thin coating of chabazite.

TYPE II

Thomsonite of this type never forms compact aggregates. The individual crystals are usually rectangular tablets of small size (1 millimeter or less), but still they are relatively much larger than the individual leaves of type I. These little tablets bunch themselves together into delicate, snow white, prismatic aggregates that frequently taper to a point or branch into smaller offshoots. The whole interior of a cavity may be thickly covered with a growth of the delicate tapering and branching prisms such as is shown in figure 2 of plate 43. Sometimes these complex prisms are so fragile that a slight pressure of the fingers will crush them. More frequently they are firm enough to stand considerable pressure, such as would be produced by wrapping in cotton and tissue paper. The complex prisms usually attain a length of a quarter to half an inch. Not infrequently thomsonite of this type forms more or less parallel continuous prismatic aggregates a quarter to half an inch thick, completely coating a cavity. In this case the appearance described above is produced by the continued growth of some of the complex prisms forming the base. Occasionally one may notice this variety of thomsonite directly coating the surface of the cavity or lying on a thin film of chabazite. Nearly always, however, a close examination will disclose an underlying layer of thomsonite of the first type. The aggregates composing this second growth do not, however, continue the growth of the first generation, but rest quite indifferently on this as a base.

TYPE IIa

No sharply defined line can be drawn between this and type II. In its best developed form it consists of similar complex, prismatic aggregates diverging regularly and symmetrically from common points so as to form beautiful delicate hemispherical bunches. At the same time the delicate prisms become longer and straighter and taper out into hair-like forms, and thus appear to pass insensibly into the mineral mesolite. These hemispherical balls may sometimes coalesce, but usually they lie quite distinct and beautifully regular. Figure 1 of plate 44 presents an excellent likeness of this habit where the prisms are fairly coarse and firm. It lies here on a continuous layer of thomsonite of the first type. Apparently types II and II*a* belong to the same generation. They do not

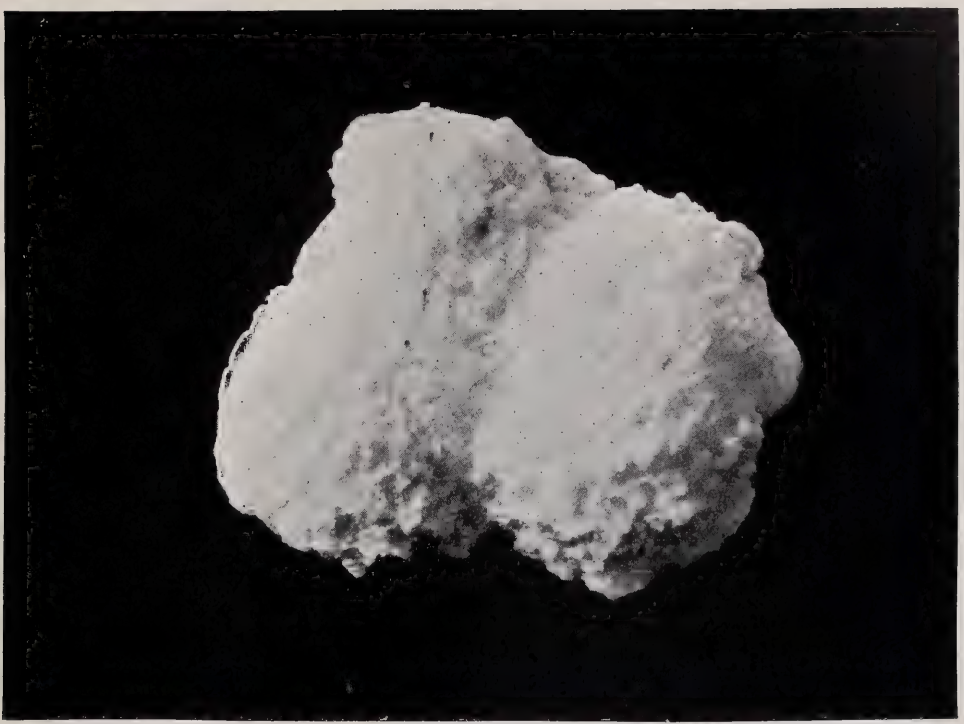

Figure 1.—Thomsonite of Type III*a*

Two-thirds natural size

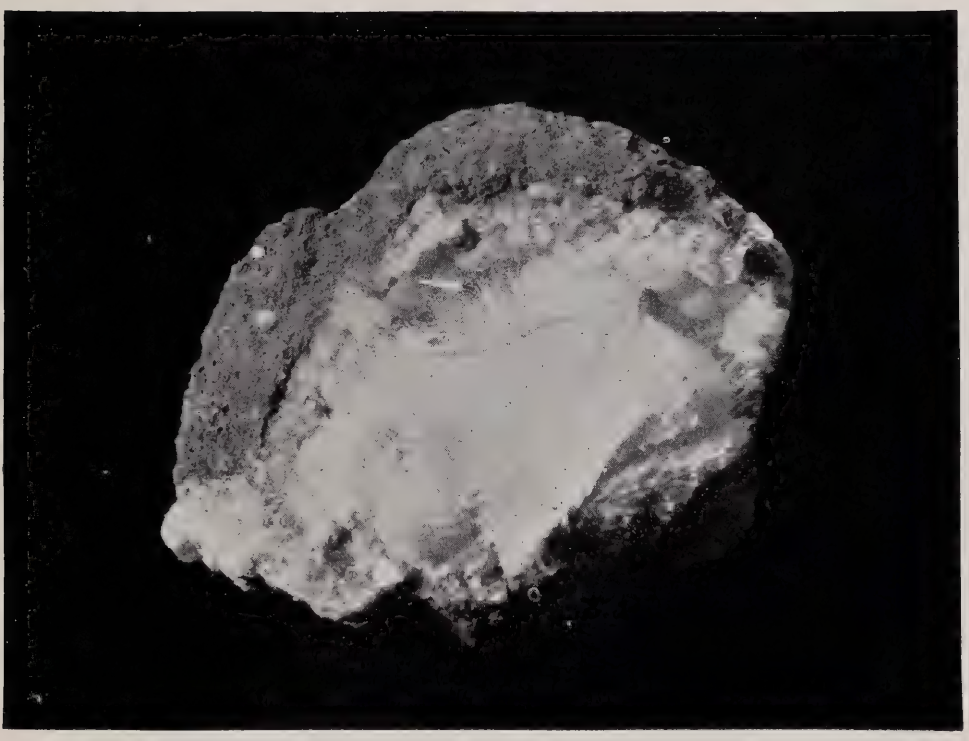

Figure 2.—Cavity lined with Chabazite and Thomsonite of Type I and of Type III

Mesolite needles continue growth of Thomsonite of Type III. Two-thirds natural size

THOMSONITE OF TYPE IIIa AND MINERAL LINED CAVITY

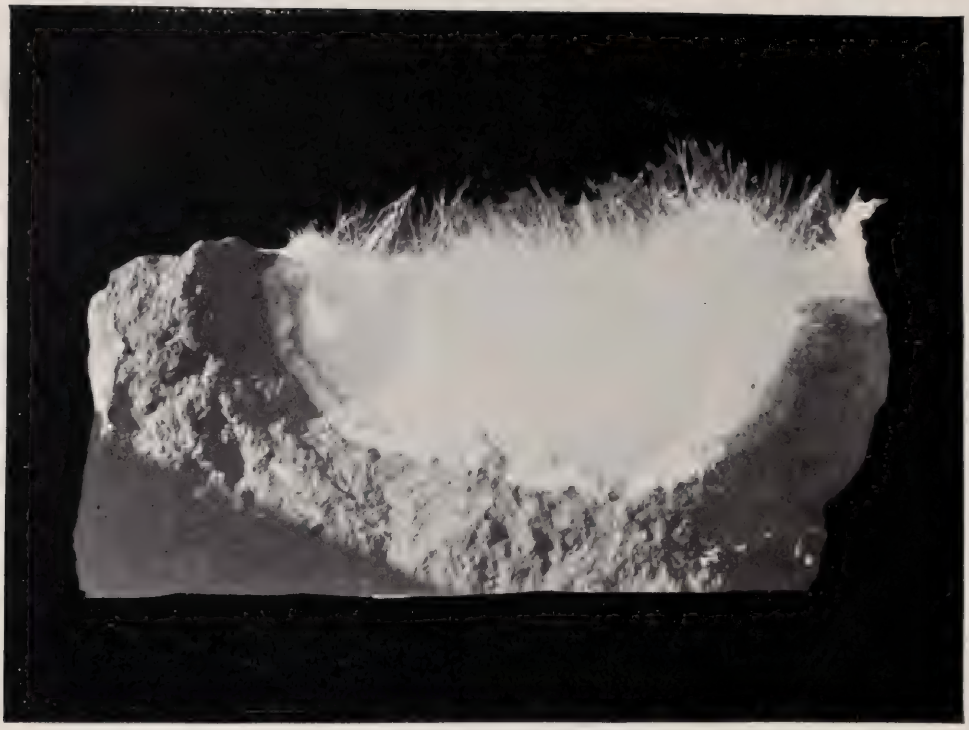

FIGURE 1.—CAVITY LINED WITH THOMSONITE OF TYPES I AND II*a*, AND FILLED WITH MESOLITE

One-third natural size

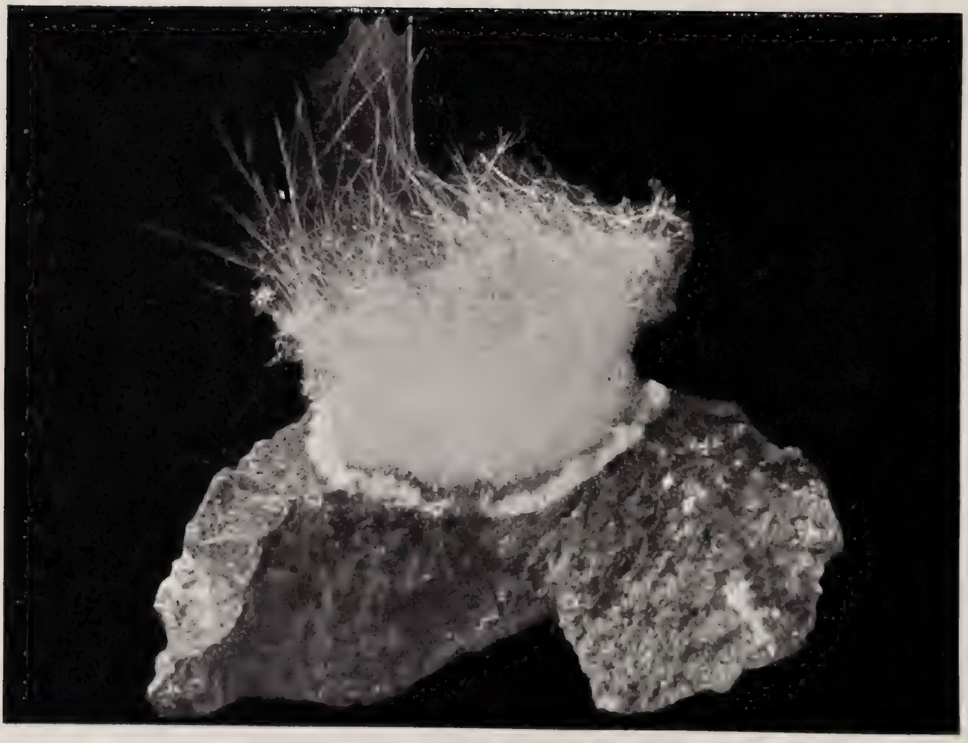

FIGURE 2.—MESOLITE GROWING ON THOMSONITE OF TYPES I AND II

One-half natural size

MINERAL LINED CAVITY AND MESOLITE

appear to occur together, but they bear the same relationships to the older and younger minerals, and are closely connected by intermediate stages.

A careful investigation of individual leaves of II and of II*a*, in parallel and convergent polarized light, revealed the same characteristics as are described under type I, with this exception: that the optical axial angle is considerably greater in leaves of types II and II*a* than in type I. Means for the determination of the optical axial angle were not at the disposal of the writer.

TYPE III

Thomsonite having this habit occurs commonly filling cavities nearly or quite full. It forms solid masses formed of radiating fairly coarse white blades that may reach a length of two or more inches. Where the cavity is not completely filled, these radiating aggregates assume hemispherical shaped forms, measuring from one to three inches across. They never terminate smoothly, but the fibers may gradually taper out into fine hairs resembling those of mesolite, or more commonly they may become covered with the rough bladed aggregates forming type III*a*. As against the older generations of thomsonite, this variety is quite distinct, although it may merge into mesolite varieties by insensible gradations. Figure 2 of plate 44 illustrates a solid amygdule composed of thomsonite of this character. It is deposited upon a coating of thomsonite of the first type, and this upon chabazite. In figure 2 of plate 45 we have a section through one of these radiated aggregates which rests upon thomsonite of the first type. The extremities of the radiating blades extend into delicate separate fibers that resemble the fine hair-like growth to be described as mesolite. Some of these fibers penetrate crystals of analcite that do not show plainly in the figure. In this case therefore the thomsonite is older than the analcite. This, however, is not always the case, for thomsonite of this habit has been observed resting upon analcite as well as on chabazite and on thomsonite of types I and II.

TYPE IIIa

The mineral is composed of thin rectangular leaves, confusedly interlaced, so as to form a very rough porous aggregate that bears a resemblance to grated cocoanut. Almost always this cocoanut-like mass is to be found on the surface of hemispherical aggregates of the type just described. Still thomsonite of type III does not always pass into this variety, and III*a* has been observed occasionally quite unconnected with III. Whether it really forms a generation by itself may be doubted. Figure 1 of plate 45 gives a fairly good idea of this habit.

Cleavage flakes and individual leaves taken from both III and III*a* show the same optical properties as do those from II and II*a*.

MESOLITE

This mineral occurs as extraordinarily delicate aggregates, composed of long, slender, hair-like fibers. They are often exquisitely beautiful, and the variety of structure and general appearance appears to be almost infinite. All the specimens thus far obtained may, however, be conveniently classified under three general types, which are designated respectively as types *a*, *b*, and *c*.

First, type *a*. The fibers form loosely felted masses that resemble fine cotton wool.

Second, type *b*. The fibers are distinct and separate, and form delicate brushes with parallel or nearly parallel bristles. This particular variety is not common. It is apt to grow on the hemispherical bunches of thomsonite of type II*a*.

Third, type *c*. The felted aggregate is composed of fibers that lie approximately in one plane, so as to form a fragile gauze or cobweb-like membranes.

Figures 1 and 2 of plate 46 and figure 1 of plate 47 represent three specimens typical of type *a*, and figures 1 and 2 of plate 48 exhibit two phases of type *c*. In figure 2 of plate 47 there is to be seen an excellent example of type *b* on the right side, while the specimen on the left is intermediate between *b* and *c*.

These three types of mesolite, as well as the numerous intermediate varieties, may be seen growing on analcite and on thomsonite of all types, but not on chabazite, as this last named zeolite is invariably first covered over by another mineral. They are very closely associated with thomsonite of types II, II*a*, III, and III*a*, and their extremely delicate fibers often appear to be but continuations of the coarser thomsonite growths that support them. More especially is this intimate association to be seen between mesolite and thomsonite of type III. Not infrequently cavities several inches in diameter (4 to 8 inches) have their centers filled with a rather dense, wool-like, matted aggregate of mesolite, while the outer portion is composed of thomsonite of type III.

But the determination of this fine fibrous mineral as mesolite depends entirely on the chemical analysis, as the fibers are far too fine to admit of a decisive physical or optical investigation. Optically about all that can be observed is a parallel extinction, with usually positive extinction.

It is perhaps well to state that at the time when this paper was prepared it was supposed that this mineral, mesolite, was really thomsonite, and specimens sent out from the Colorado School of Mines were so labeled.

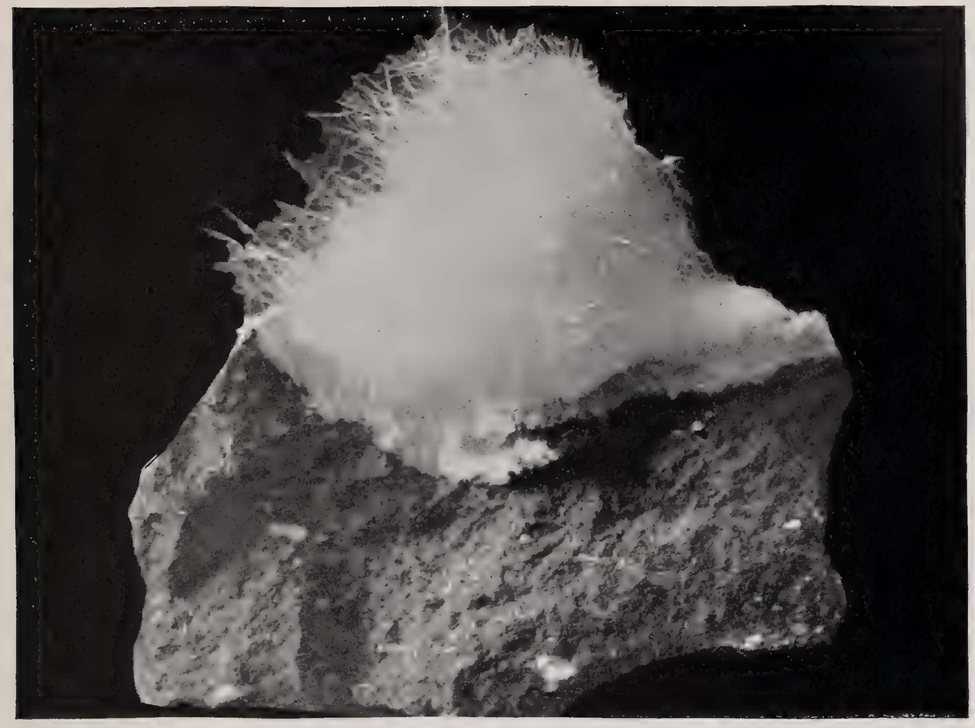

FIGURE 1.—MESOLITE GROWING ON THOMSONITE OF TYPE II

One-half natural size

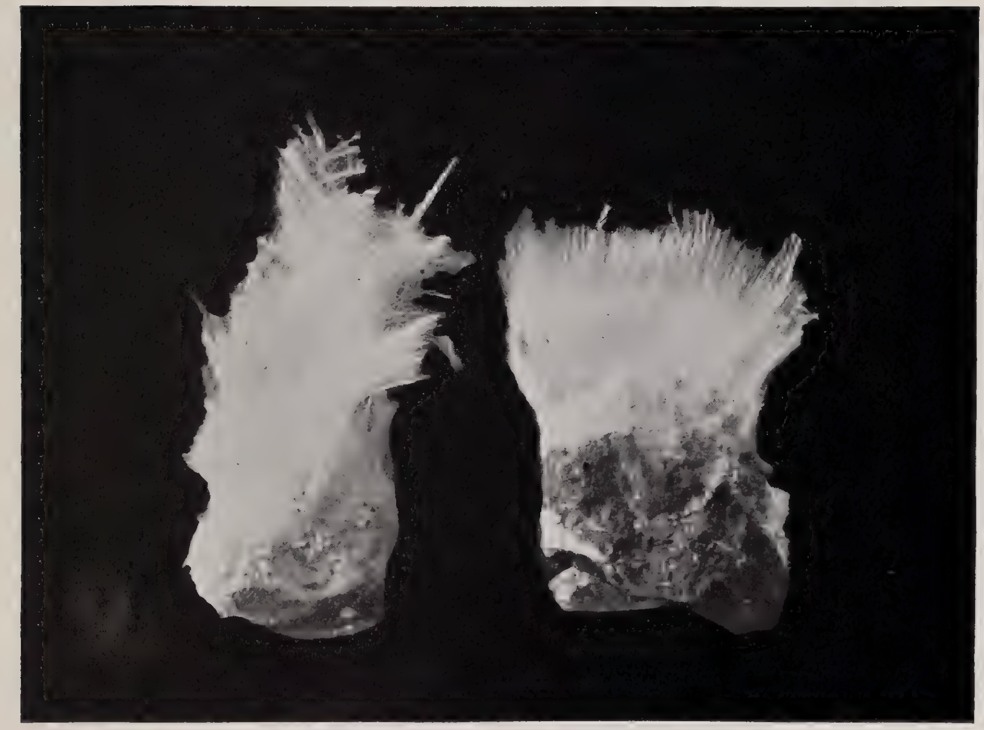

FIGURE 2.—MESOLITE GROWING ON THOMSONITE OF TYPE II*a*

Two-thirds natural size

MESOLITE GROWING ON THOMSONITE

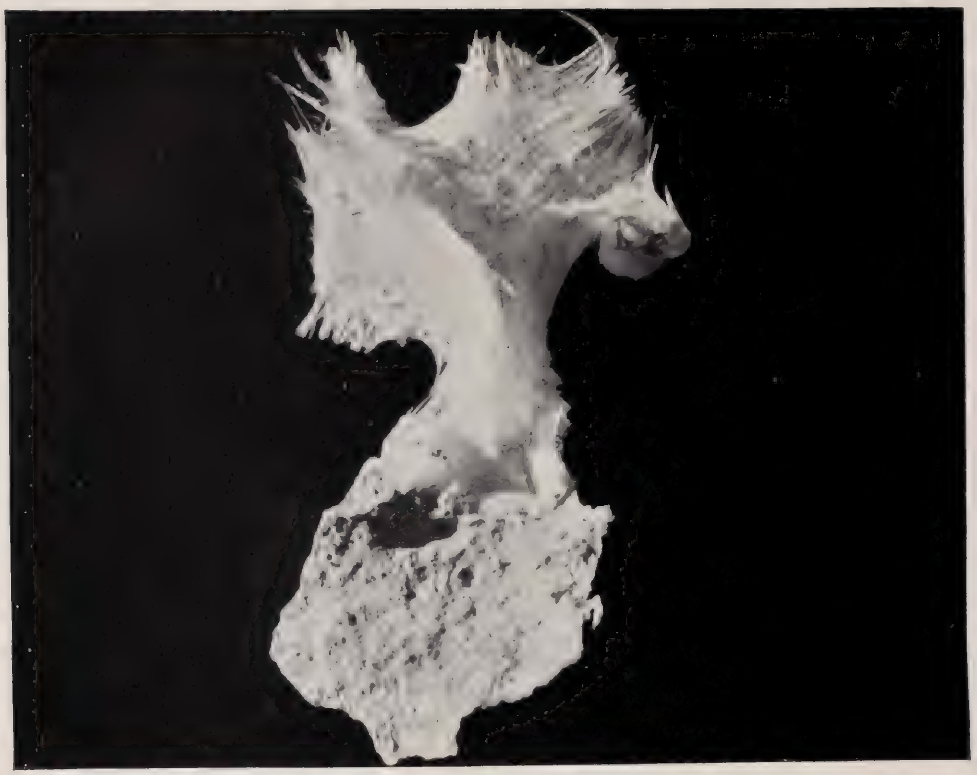

Figure 1.—Mesolite growing on Thomsonite of Type II*a* and Analcite

Two-thirds natural size

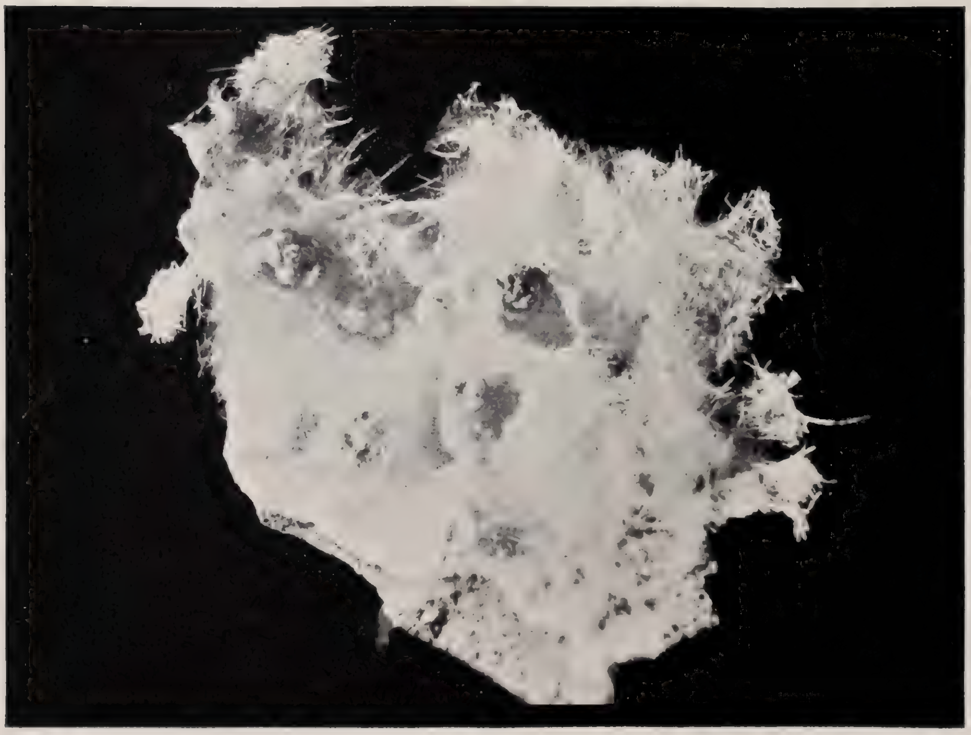

Figure 2.—Mesolite growing on Thomsonite of Type II

One-half natural size

MESOLITE GROWING ON THOMSONITE AND ANALCITE

This determination as mesolite was based on a carefully made chemical analysis, which apparently closely coincided with analyses of undoubted thomsonite from Table mountain and elsewhere; but inasmuch as Cross and Hillebrand had published analyses of an apparently identical mineral from Table mountain, and had determined the mineral to be mesolite, it seemed advisable to submit the material in question to a renewed investigation. The result showed that the material used for the first analysis was not absolutely pure, but contained just enough carbonate of calcium to make the analysis closely approximate that of thomsonite. The material on which the later analysis was made was obtained at a later date and proved to be perfectly pure.

Chemical Analyses

The chemical analyses given below were carried out in the chemical laboratories of the Colorado State School of Mines. Analyses 1 and 2 were made by President Regis Chauvenet, and number 3 by Doctor Robert N. Hartmann. In presenting these analyses the author wishes herewith to acknowledge gratefully the valuable assistance thus rendered. In all three cases great care was exercised to secure absolutely pure material. Number 1 was taken from thomsonite of type II and was obtained by carefully breaking off the freely projecting needles and prisms. Number 2 was taken from the center of a mass some 2 inches in diameter and represents thomsonite of type III. Number 3 represents a fine cotton-like mass of mesolite. For purposes of comparison, five analyses are also given which were made by W. F. Hillebrand* from material collected by the U. S. Geological Survey from Table mountain. Judging from the descriptions accompanying these analyses, IX and X represent thomsonite of type I, while XI and XII represent either type II or type III. Number XVIII is mesolite.

	Number 1.	Number 2.	Number 3.	IX.	X.	XI.	XII.	XVIII.
SiO_2	41.34	41.59	45.59	40.88	40.68	41.21	42.66	46.17
Al_2O_3	30.35	30.59	25.18	29.68	30.12	29.71	29.25	26.88
CaO	11.20	11.15	8.93	11.88	11.92	11.34	10.90	8.77
Na_2O	5.04	4.66	7.65	4.72	4.44	5.62	4.92	6.19
H_2O	12.27	12.24	12.67	12.91	12.86	12.20	12.28	12.16
	100.20	100.23	100.02	100.07	100.02	100.08	100.01	100.17

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* Bull. No. 20, U. S. Geol. Survey, pp. 25, 35.

For the purpose of checking analysis number 3 a corroborative test for silica was made on another sample of mesolite, which gave $SiO = 44.83$.

The following description of the method pursued in the analysis of mesolite has been furnished by Doctor Hartmann. The mineral was air-dried and analyzed by the method customarily employed with silicates decomposed by HCl. H_2O was determined by cautious ignition at a low red heat, and the residual silicate used for further analysis. The silica was treated with ammonium fluoride and Na_2SO_4 to test the purity. The sodium was weighed as sulphate obtained by ignition of the salts of the evaporated filtrate from the calcium determination with H_2SO_4. Platinum vessels were used wherever possible.

Chabazite

Chabazite is the commonest of the zeolites found on the Table mountains at Golden. It forms thin crusts lining the smaller cavities, and is invariably the oldest mineral deposited. It is difficult, however, to secure good specimens of this mineral without retaining a large piece of the inclosing basalt. This is due to the brittleness of chabazite and to the fact that the crusts are always very thin, so that when separating from the rock the fragile crusts break into small fragments.

In their description of this mineral as it occurs on North and South Table mountains Cross and Hillebrand state that it occurs in simple rhombohedrons or in plain rhombohedrons twinned parallel to the basal plane. With the exception of the locality from which the zeolites described in the present paper were obtained, it is true, as far as the observation of the writer goes, that the chabazite crystals are invariably simple or twinned rhombohedrons. It is all the more surprising, therefore, to find that at this particular quarry the chabazite crystals possess a far more complicated form than has been observed before.

The chabazites of this locality vary from white to reddish in color, and in size from 5 to 10 millimeters. Not infrequently both white and reddish crystals may be found on the same specimen. There are a few simple rhombohedrons that show interpenetrating twinning such as are to be seen at other localities on the same mountain; but in nearly all cases the form is not only twinned, but is quite complex. The following forms may be identified on most of the crystals: $+R(10\bar{1}1)$, $-2R(02\bar{2}1) = s$, $-\frac{1}{2}R(01\bar{1}2) = e$, $\infty P2(11\bar{2}0) = a$; also two scalenohedrons.

Figure 2 of plate 49 is intended to represent one of these twinned crystals in its customary development. In the general distribution of

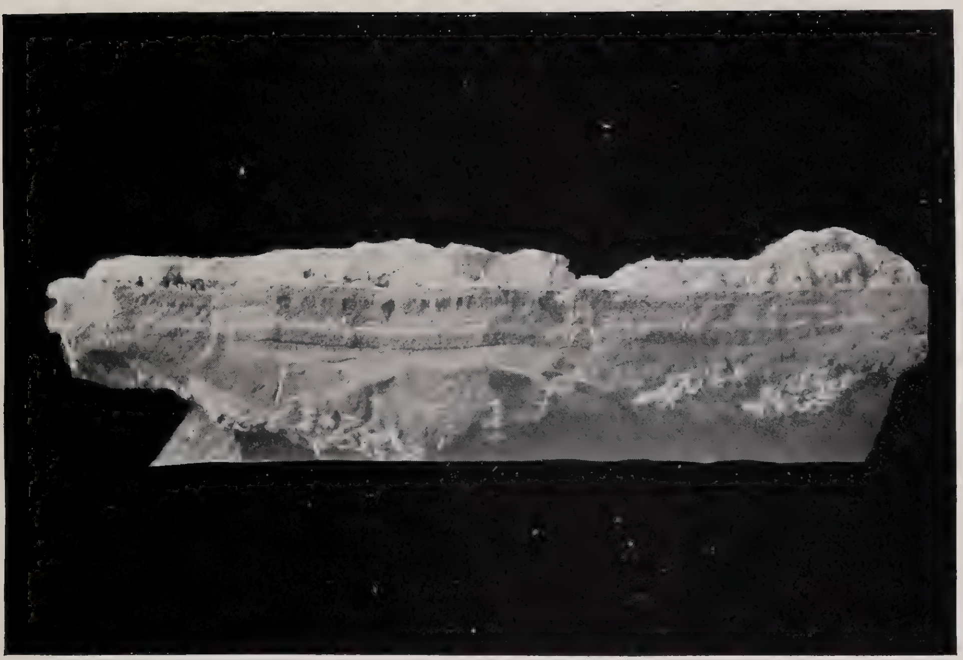

Figure 1.—Floor of mixed Laumontite and Stilbite

Floor is composed of layer of Laumontite, 1/8 inch thick, isolated Analcite crystals and layer of Thomsonite of Type II, 3/8 inch thick. One-third natural size

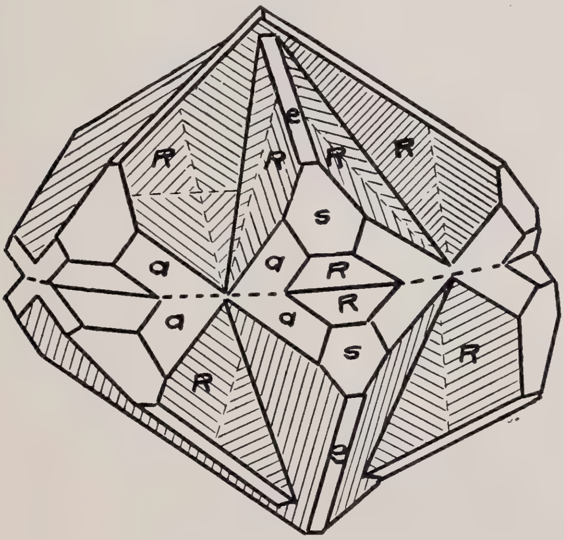

Figure 2.—Drawing of Crystal of Chabazite

FLOOR OF LAUMONTITE AND STILBITE AND DRAWING OF CHABAZITE CRYSTAL

the faces and slight distortion it fairly well represents an actual crystal, although the crystal as it occurs does not show all the faces represented in the drawing. It is very common to find one of the interpenetrating crystals smaller than the other, as is shown in figure 2 of plate 49, but other crystals show every possible degree of distortion of one or both of the two individuals. In many cases one of the interpenetrating individuals may be almost suppressed or, what amounts to the same thing, may show just a corner of the rhombohedron projecting from the face of the other and larger individual; but, with all the varying degrees of distortion and suppression, three of the forms are almost always to be seen. These are R, $-2R$, and $\infty P2$—that is, R, s, and a. The flatter rhombohedron e is very often missing, or is present on one and missing on the other twinned individual.

The two scalenohedrons are never present as distinct faces, but as strongly developed striations. Nevertheless they are well enough developed to give distinct flashes of light. By their intersections they form flat ridges upon the faces of the rhombohedron R. Almost always one of these striating scalenohedrons may be detected, while the other one is mainly absent.

The more common of the two scalenohedrons striates R parallel to the rhombohedron edges that meet at the vertex of the crystal—that is, parallel to the edge formed by R and e. It forms by the intersections of the striations a very flat ridge on the face of R, running from the top of the crystal down toward the middle of the face. The other scalenohedron striates R on the lower part of the face parallel to the zigzag edges—that is, parallel to the edge formed by R and a. It forms a flat ridge that runs from the point of intersection of two lateral edges upward till it meets the ridge formed by the other scalenohedron. By their mutual intersections these two scalenohedrons also form two horizontal flat ridges. Thus four ridges are formed that divide the face R into quadrants. The above description of the striating scalenohedrons applies, of course, only to ideally or symmetrically developed crystals, such as are never realized in nature. As a matter of fact, only occasionally do the striations approach to symmetry. In nearly all cases the flat striation ridges are shoved to one side or the other or are entirely crowded off. An attempt to illustrate this distortion of the scalenohedral striations is made in the shading of the faces of R in figure 2 of plate 49.

As far as is known to the writer, the chabazite crystals that are most nearly akin to these from Golden are the crystals from the phonolite near Rübendörfel, in Bohemia.* These crystals from Rübendörfel (commonly labeled as from Aussig) show scalenohedral striations and also similar forms and twinning, but lack the prism *a*.

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* Doctor C. Hintze: Handbuch der Mineralogie, Leipzig, 1897, p. 1777.

OTHER ZEOLITES

ANALCITE

The other zeolites present may be dismissed with a very brief mention, inasmuch as they have already received ample description. Next to thomsonite analcite is the most abundant zeolite present. The milky white variety is the most abundant, but clear glassy crystals are not wanting. In size they vary from 1 millimeter up to 2½ inches in diameter. Specimens measuring 1 inch are common. They sometimes occur alone, lining the cavities on all sides, but more frequently they lie on a coating of chabazite or of thomsonite of types I and II. The form is the characteristic trapezohedron $2\,O\,2$ (211), sometimes with the edges running to the center of the octant slightly truncated by the trisoctahedron $\frac{3}{2}O$ (332). Its period of growth about corresponds with that of thomsonite, type III, as it occurs sometimes beneath this variety, sometimes penetrated by its needles. In one case a few minute crystals of analcite were observed growing upon the very delicate hairlike fibers of mesolite. This would indicate that analcite occurs here in two generations.

APOPHYLLITE

Apophyllite is very sparingly represented by snow-white opaque crystals, with the characteristic steep pyramid and indirect prism. It occurs in crystals from a quarter to half an inch in length ; is always associated with analcite and always imbedded in and therefore older than that mineral.

STILBITE AND LAUMONTITE

Stilbite and laumontite occur, as described by Cross and Hillebrand, forming the bedded floor of many cavities, and also as larger and distinctly crystallized specimens growing freely on the upper surface of the bedded floors. A second generation of both of these minerals has been noted in a few cases. In one case snow-white crystals of laumontite showing the customary square prism and steep orthodome occur, growing on a quarter-inch layer of thomsonite, which forms the uppermost deposit of the bedded floor. These laumontite crystals measure from 5 to 10 millimeters in length and half a millimeter or more in thickness. The position of this thomsonite layer with reference to the order of deposition is not clear, but it resembles type II more closely than any other.

CALCITE AND ARAGONITE

Calcite is only occasionally present in scalenohedral crystals. Its position appears to lie between thomsonite, type III, and mesolite. Aragonite is more commonly present. It is the very latest mineral deposited, and occurs in thin transparent or whitish coatings on most of the younger minerals.

Order of Deposition

The minerals here described, as well as their different varieties, occur so frequently associated together that, for most of them, the order of deposition is very readily observed. For the purpose of ready comparison, the order as determined in the new locality and that given by Cross and Hillebrand are placed in parallel columns.

Order of deposition in new locality.	Order of deposition observed by Cross and Hillebrand.
1. Laumontite.	1. Laumontite.
2. Stilbite.	2. Stilbite.
3. Chabazite.	3. Thomsonite.
4. Thomsonite, type I.	4. Calcite (yellow).
5. Apophyllite.	5. Stilbite.
6. Thomsonite, types II and II*a*.	6. Chabazite.
7. Laumontite.	7. Thomsonite.
8. Stilbite.	8. Analcite.
9. Analcite.	9. Apophyllite.
10. Thomsonite, type III.	10. Calcite (colorless).
11. Calcite.	11. Mesolite.
12. Thomsonite, type III*a*.	
13. Mesolite.	
14. Analcite.	
15. Aragonite.	

The differences between the two will be seen to be very slight, and can mostly be accounted for by the recognition of a second period of laumontite deposition and of the different stages of thomsonite formation.

Summary

In a newly opened quarry on the east face of North Table mountain at Golden, Colorado, are found a great variety of zeolites of which thomsonite, mesolite, and chabazite are the most important. These occur sometimes separately, filling or lining adjacent cavities, but more often in successive deposits in the same cavity. The thomsonite is chiefly remarkable for the great variety of types in which it occurs, each type representing a distinct generation. A microscopical investigation indicates that the brachypinacoid is the dominant form, instead of the macropinacoid, as formerly supposed.

The mesolite is distinguished both by great variety of type and by exquisite beauty and delicacy. Chabazite occurs in crystals that show twinning parallel to the basal plane and an unusual development of forms.

The zeolites, together with calcite and aragonite, as they occur here, indicate no less than fifteen distinct stages or periods of mineral deposition.

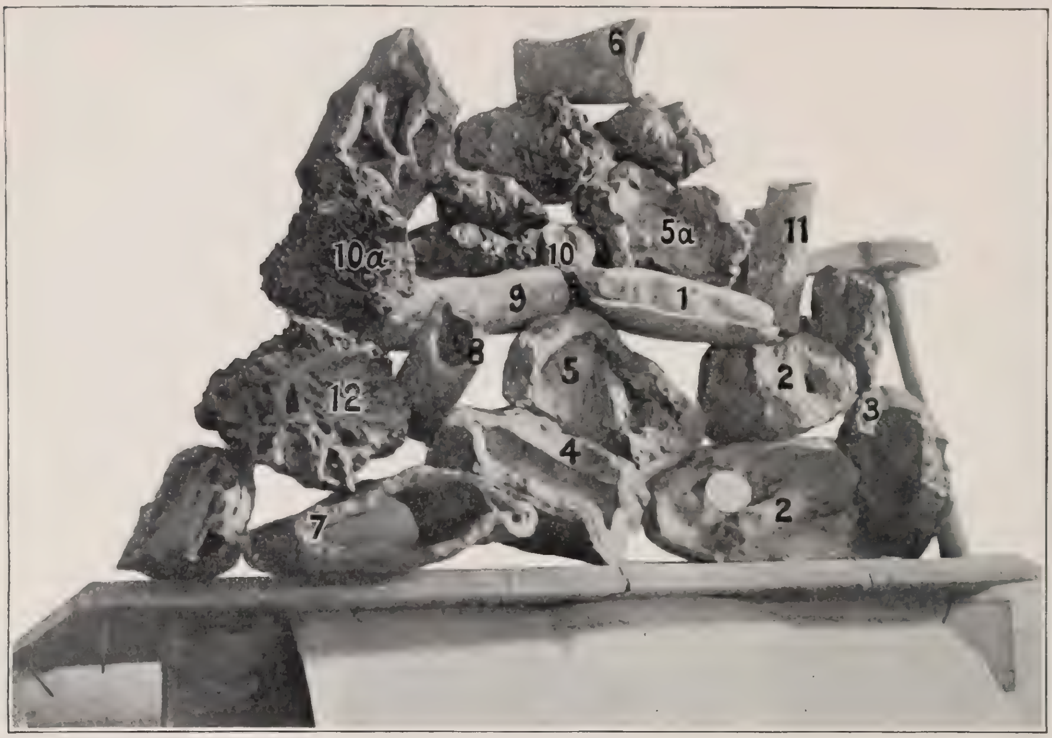

Figure 1.—Samples of Limonite Ore

Numbers 1-5, bombshell ore; 6-11, pipe ore; 12, brecciated ore

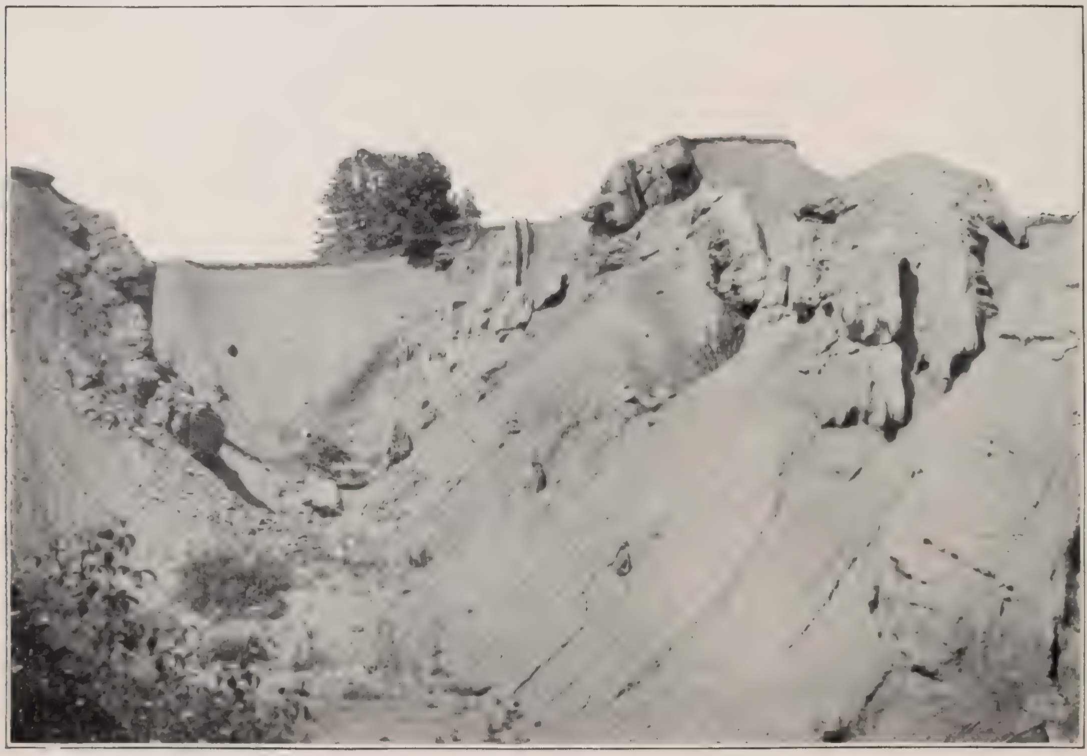

Figure 2.—View in the Hunter Ore Bank

Showing an ore pocket in eroded cavity in the limestone

LIMONITE ORE AND ORE POCKET

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CAMBRO-SILURIAN LIMONITE ORES OF PENNSYLVANIA

BY T. C. HOPKINS

(Presented before the Society December 30, 1899)

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INTRODUCTION

The object of this paper is to explain the genesis of the limonite ores of the limestone valleys in central and eastern Pennsylvania, to show the original sources of the iron, the modes of its accumulation, and to account for its frequent occurrence along with more or less extensive bodies of white and parti-colored clays. The data and conclusions presented are based on field studies of the limonite ores of the limestone areas in the Great valley and in portions of Nittany valley.

The occurrence of limonite ores in Pennsylvania has been known a great many years; in fact, they have been employed in the manufacture of iron ever since that industry began in this country. They occur in every geological formation and in every county in the state, but this paper treats only of those in the limestone valleys of the central and eastern portions and the closely associated ores of the underlying slates. What is said will apply equally well to many similar deposits along the Great valley of the Appalachians, but it is not intended primarily to include all of the Great valley deposits, or any part of them outside of Pennsylvania.

Much has been written about these limonite deposits, and many explanations have been offered to account for them. While the different hypotheses heretofore advanced have been taken into consideration, the conclusions in this paper are, as previously stated, based primarily on field observations made by the writer during the years 1898 and 1899.

GEOLOGICAL POSITION OF THE ORES

The limonite ores in question occur in residual deposits on the Ordovician and Cambrian limestones and slates. They are referred to in literature as the Cambro-Silurian ores, signifying that they occur partly in the Cambrian and partly in the Silurian rocks, but that portion of what was formerly called Silurian is now more commonly called Ordovician. The Ordovician portion of the series is included in the number II or Trenton group of the classification of the Second Pennsylvania Geological Survey. Trenton, as thus used, includes all the Ordovician below the Utica shale. The lower portion of the series, including the slates and quartzites, is called group number 1 or " Chiques quartzite " by the Pennsylvania Survey. In the earlier reports it was correlated with the Potsdam of New York, but Lesley in his later reports advised the use of the local term, Chiques or Hellam. Walcott's more recent investigations* show that the quartzite, slates, and some of the limestones carry the Olenellus fauna, and hence are Lower Cambrian. The Upper and Middle Cambrian faunas have not been determined in this area, except the lower horizon of the Middle Cambrian in one locality. The upper portion of the limestones carries the Trenton fauna, and a few Chazy and Calciferous forms have been found in lower portions, but the strata between the Trenton at the top and the Lower Cambrian have so far shown no well defined fauna, and have not been carefully classified. It has not been possible even to draw a definite boundary between the Cambrian and the Ordovician, so we are compelled to still speak of the strata in their entirety as Cambro-Ordovician. It is on them that the ores in question occur, some near the top of the Trenton, some on the Lower Cambrian, and many over the vague horizons between these limits.

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* Bull. No. 134 of the U. S. Geol. Survey.

It should be noted, however, that the ore deposits in large measure are on and not in the rocks of this age—that is, they are residual deposits and have been formed since the uplift of these beds in late or post-Permian time. The process of formation is going on at present and has been presumably more or less continuous since Carboniferous time.

Description of the Ores

ASSOCIATED MINERALS AND CLASSIFICATION

The bulk of the ores consists of the mineral limonite, associated with which are variable quantities of the other hydrous oxides, turgite and goethite, and the anhydrous oxides, hematite and magnetite.*

The ores occur in many diversified forms, which might be variously classified, but for convenience the following group names, based on form, are used by the author: nodular ore, pipe ore, brecciated ore, flake or sheet ore, fragmental ore, and yellow ocher.

NODULAR ORE

The nodular ore consists of irregularly rounded masses, varying in size from a fraction of a pound to several hundred pounds in weight. The masses are frequently hollow (see numbers 2 and 3 in plate 50, figure 1), but some inclose a rounded or subangular rock fragment (see number 1 in figure 1), which is sometimes sandstone, as in the illustration, sometimes chert, sometimes slate, and sometimes clay. Some of the shells are filled with clay or sand, and workmen report finding many of them filled with water. Some are filled with clay, which still retains the laminated structure and appearance of the original slate from which the clay was derived. Furthermore, this slaty structure was found to extend through the ore shell, which showed, besides the plain lamination of the slate, a faint concentric structure as well. This shell, which is illustrated in figure 1, was not found imbedded in the slate, but in the loose material on an outcrop of it where it occurred along with many similar ones. It was clearly a concretionary form in the slates, an advanced stage of the concentric structure that may be seen in almost any shale bed. While only one shell was found still retaining the laminations in the clay, there were many others containing clay and sand. Some of the shells are but thin crusts, while others are quite thick, almost solid; some have a rough irregular inner surface, while others have a smooth, velvety or bright mammillated inner surface, frequently coated with manganese oxide. In some instances the lining of the shell is covered with a great many small stalactites of ore, indicating a deposit on the interior since the shell was formed. Many of the shells are lined with a dense fibrous layer, often an inch or more in thickness. The last two varieties resemble some of the quartz geodes and indicate a similar origin. The thinner shells have nearly all been broken, and we see only the fragments of them in the clay-ore masses. This shell form of the ore is common throughout the area and forms an appreciable part of the ore body in many places. The small, irregular, nodular-like pieces of ore, commonly known as shot ore, are presumably closely related in origin to the shells, the difference being that the segregation was around more numerous centers, and hence resulted in smaller pieces.

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*The extensive deposit of magnetite at Cornwall, Pennsylvania, while occurring at about the same geological horizon, is so intimately associated with igneous dikes that it will not be considered with the limonite deposits.

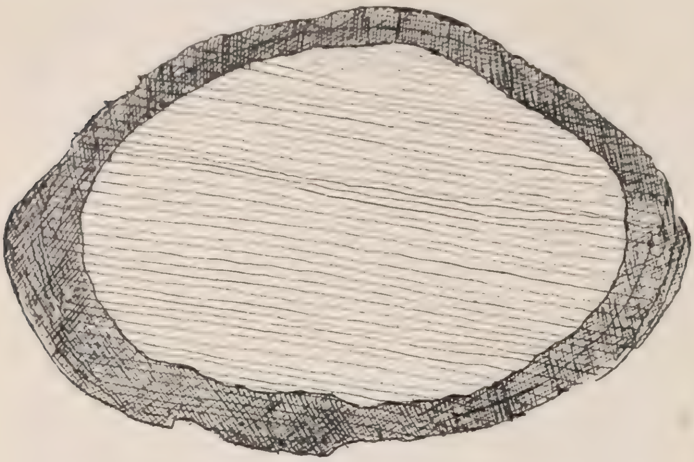

FIGURE 1.—*Cross-section of Ore Nodule from Cambrian Slates.*

PIPE ORE

Pipe ore comprises two distinct types, one of which (illustrated by numbers 6, 7, 8, 9, and 11 in plate 50, figure 1) consists of heavy compact pipe-like masses from 1 or 2 to 8 or 10 inches in diameter, the ore crust being from a fraction of an inch to 3 inches or more in thickness. In nearly all cases this type of pipe ore is impregnated with clay, grains of sand, and other foreign material. The inference is that the iron oxide was deposited around lime stalactites or stalagmites which were subsequently leached out and carried away. The presence of the sand and foreign material in the oxide suggests that the lime stalactites were imbedded in the clay and sand when the deposition of the iron took place. The other type of the pipe ores consists of a loose aggregation of slender pipes or rods, all having a general parallelism and each pipe cemented to its neighbors at frequent intervals. The iron oxide is comparatively free from impregnating foreign material. Somewhat similar forms of lime carbonate have been observed where the waters from a lime spring trickle over an overhanging, jagged ledge of rock, either on the surface or in a subterranean cavity, and the inference is that the pipe ores have been formed in a somewhat similar manner. They have all been broken from their original position, and are now found only in fragments intermingled in the clay mass. The pipe ores have not been observed in the sandstone or slate areas, but are abundant in limestone ore regions, in some places forming the major part of the ore.

BRECCIATED ORE

The brecciated ore consists of fragments of chert, sandstone, or slate, cemented by iron oxide into a solid mass. These masses are sometimes quite large, many tons in weight, forming so-called solid ore bodies. Frequently the inclosed rock fragments disintegrate and crumble out, leaving the more or less cavernous skeleton of ore (see number 12, plate 50, figure 1). Brecciated ore is found on the limestones, on the clay, and on the sand deposits. It occurs in large quantities on the sand deposits in the Nittany valley, where the greater part of the inclosed fragments consists of chert from the overlying limestones. I have nowhere observed any limestone fragments in any of the brecciated masses. It is possible that some of the hollow spaces may represent former limestone fragments which have all been leached out. The brecciated ores are most abundant where the ore masses rest on the sandstone or intercalated clay beds, and while in general they are most abundant near the bottom of the deposit, huge blocks of them are scattered at various levels through the clay-ore mass.

FLAKE OR SHEET ORE

Flake or sheet ore occurs in the joint and bedding seams of the limestone and slates. So far as it has been observed *in situ* it occurs in comparatively thin flaky laminated sheets, often less than an inch in thickness (see figures 2 and 4). As the surrounding rock is leached away, the ore sheets and flakes are carried down and more or less broken up and mingled with the other materials. The nature of the ore fragments observed in the residual clay shows this type of ore to be locally the most abundant of all those mentioned, while in other localities it is almost entirely wanting.

FRAGMENTAL ORE

Fragmental ore consists of irregular angular fragments of all sizes commingled with the residual clay, being probably in all cases broken remnants of the preceding forms. It is not always possible, however, to refer the fragment to its original form, as there is often no essential difference in appearance between a small fragment of a sheet and that of a pipe or a shell. In several localities, most noticeably in the limestone districts, there are rounded water-worn fragments of the ore associated with partly rounded chert and sandstone pieces. These are local in occurrence and form a comparatively small part of the ore deposits. They may be caused in part by surface and in part by subterranean streams. An especially favorable point for them is at the bottom of a sink-hole, where the surface waters pouring in during the wet seasons wear the materials at the bottom like the pebbles in a brook. The subsequent decay of the limestone buries the rounded materials in the residual clay and obscures the manner of their formation. These sink-holes are quite abundant at the present time, and in the few places where the bottom is accessible the rounded fragments of ore and chert are quite numerous.

YELLOW OCHER

Yellow ocher, while not properly an iron ore, is probably the most common form of the iron oxide in the region considered. It is associated with the ores in all the deposits, and in many places occurs free from lump ore. It represents the diffused iron oxide which has not been segregated. In several places it is prepared for market as ocher, but generally no attempt has been made to save it.

Chemical Composition

The following analyses of carefully selected samples show the chemical nature of the ores. Commercial analyses of carload lots give a much lower per cent of iron and a corresponding increase of silica and alumina, as shown in analysis number 8 of the table, which gives the average of 29 analyses, each of which represents 150 to 500 specimens of ore. The commercial analyses include considerable mechanical impurities in the form of clay and sand that were eliminated as far as possible in the other analyses. Doctor Genth, who made most of the analyses, says the ores are mechanical mixtures of limonite with hydrous ferric silicate and minute traces of hydrous ferric phosphate. It is impossible, he says, to state whether the hydrous ferric silicate is anthosiderite or degeroite, or, he might have added, one or more of several other hydrous ferric silicates, of which chloropal is a common form. There is a possibility also that some of it may occur as grünerite or some other iron, or iron-magnesian, amphibole, or pyroxene. Bischof* says that hydrate of iron will decompose silicate of alumina. The deposition of the ores in contact with the clays and cherts would furnish opportunity for such chemical reaction. That the waters carrying the iron have a chemical action on the silica is shown by the dissolution of the chert, shale, and sandstone fragments inclosed in the shells and the breccias.

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* Elements of Chemical and Physical Geology, vol. 2.

Analyses of selected Specimens of Limonites

	1.	2.	3.	4.	5.	6.	7.	8.
	Pipe ore, Hostler bank.	Pipe ore, Pennsylvania bank.	Pipe ore, Hunter bank.	Pure fibrous, Dry Hollow bank.	Pure fibrous, Bull bank.	Amorphous compact brown ore, Lytle bank.	Clean dark brown ore, Centre county.	Average of 29 commercial analyses.
Fe_2O_3	78.58	83.74	78.57	83.13	81.48	82.00	68.26	62.11
MnO_2	.08	.31	.01	.15	.07	Tr.	.19	2.85
Al_2O_3	.88	.33	1.21	.74	.49	1.94	.28	2.39
MgO	.54	.34	.55	.09	Tr.	.17	.08	.42
CaO	.30	Tr.	.62	Tr.	Tr.	Tr.	.07	.48
P_2O_5	.36	.14	.36	.50	.08	.37	.96	1.10
SiO_2	4.25	2.57	7.65*	2.47	3.98	2.98	16.13*	18.97
Quartz	2.60	.44	......	......	......	.44	......	......
H_2O	12.41	12.13	11.16	12.92	13.00	12.10	12.24	11.62
S	......	......	.028	......	......	......	.011	.06
Total	100.00	100.00	100.19	100.00	100.00	100.00	98.22	100.00

Numbers 1, 2, 4, 5, and 6 analyzed by F. A. Genth.
Number 3 by A. S. McCreath.
Number 7 by John I. Thompson, Lemont, Pennsylvania.

Some of the dissolved silica may enter into chemical combination with the iron; some of it may simply be carried down with the iron in minute particles. The deposition of the iron in the presence of minute particles of clay might inclose some of the particles without any chemical action, and the association be so close and the included particles so minute that they could not be separated by any mechanical means. The phosphorus may occur in combination with the iron as vivianite, triplite, or some of the associated forms, or perhaps as a basic ferric phosphate, or it may be in combination with the alumina. Evidence favoring the latter supposition is the prevalence of wavellite, which occurs in large quantities closely associated with the ores in several localities (see page 483), and the occurrence of ceruleolactite in the ore mine in Chester valley.

The phosphorus will probably form a hydrous phosphate, whether it combines with the iron or the alumina. The remaining alumina probably is in combination with silica and water. This will not leave sufficient water to form limonite with all the iron, in the molecular ratio commonly given, namely, $2Fe_2O_3$, $3H_2O$. In fact, if all the water combines with the iron, it is not sufficient to form the theoretical limonite. Hence we must assume either that the water and iron combine in a different ratio and form a new compound or, what is more probable, that there is a mixture of the limonite and one of the other hydrous oxides.

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* Insoluble residue. The analysis of the insoluble residue in number 7 gave: $SiO_2 = 13,505$ Al_2O_3 2.4, CaO .078, MgO .147.

I have computed the hypothetical combinations of the elements given in analysis number 1 on two bases, first assuming that the phosphorus combines with the alumina to form wavellite, and, secondly, that it combines with iron to form vivianite, and the silica combines with iron to form grünerite. If one of the hydrous ferric silicates is formed, the proportions would be changed slightly, as shown in a third combination. After forming the wavellite, the remaining alumina is put in the form of kaolin, and the remaining water and iron are combined so as to form all the limonite possible, and the iron in excess is put into the goethite, the next highest oxide.

1.		2.	
	Per cent.		*Per cent.*
Limonite, $2Fe_2O_3, 3H_2O$	77.79	Limonite	75.65
Goethite, Fe_2O_3, H_2O..........	8.07	Goethite.....................	9.61
Grünerite, $FeSiO_3$............	8.40	Grünerite....................	8.59
Wavellite....................	.78	Vivianite....................	1.95
Kaolin	1.30	Kaolin	8.70

The small per cent of manganese is supposed to be in the form of the oxide. The lime and magnesia are presumably in the form of the carbonate.

Hypothetical Combinations of the Elements in the Limonite Ores

Computing the excess Silica as Anthosiderite

	No. 5.	No. 1.	No. 2.	No. 6.
	Bull bank.	Hostler bank.	Pennsylvania bank.	Lytle bank.
Limonite............	92.80	65.72	54.23	44.51
Goethite.............	....	23.49	39.95	44.70
Anthosiderite, $2Fe_2O_3, 9SiO_22H_2O$..	5.91	4.05	4.06	2.39
Wavellite............	.39	.993	.45	.76
Kaolin.	.77	1.29	.26	3.61
Quartz......	....	2.60	.44	.44
$Fe_2O_3 : H_2O$ (molecular)	496 : 747 2 : 3 nearly limonite.	478 : 652 3 : 4 nearly.	515 : 660 4 : 5 nearly.	506 : 625 4 : 5 nearly.

Computing the excess Silica as Chloropal.

Limonite	63.60	34.78	36.85	33.66
Goethite	26.52	50.73	59.10	57.85
Chloropal, Fe_2O_3, $3SiO_2 5H_2O$	8.60	8.62	5.92	3.01
Wavellite	.39	.99	.45	.76
Kaolin	.77	1.29	.26	3.61
Quartz	....	2.60	.44	.44
$Fe_2O_3 : H_2O$ (molecular)	489 : 660 3 : 4 nearly.	471 : 564 4 : 5 nearly.	510 : 599 5 : 6 nearly.	505 : 595 5 : 6 nearly.

If the silica is combined with the iron in the form of anthosiderite, it will be seen that the remaining iron and water in number 5 will be in the proper ratio to form limonite, and hence this seems a probable combination; but in numbers 1, 2, and 6 the iron and water are in the proportion of 3 : 4 and 4 : 5. If chloropal is formed, the iron-water ratio is 3 to 4, 4 to 5, and 5 to 6. It is possible that iron and water may combine in these variable ratios; but until it can be proven in some way, it seems better to consider them as forming mixtures of the established compounds, limonite and goethite or turgite.

Chloropal has been found associated with the iron ores in at least one locality in Lehigh county, and it is likewise a better known mineral than anthosiderite, and in this respect its occurrence is more probable.

Associated Minerals

Besides the iron oxides already mentioned, namely, limonite, goethite, turgite, hematite, and magnetite, the other iron minerals present in the ore deposits are ilmenite, siderite, and iron pyrite.* Manganese is associated with the iron ores in many places, and in several different localities the manganese oxides, psilomelane, and pyrolusite have been mined and shipped. The analyses show the presence of manganese in all the ores.

Wavellite occurs associated with the iron ores in several localities, and in one place near Mount Holly Springs it is found in commercial quantities. At Glen Loch the wavellite occurs in crystal forms in the old iron ore pit. Quartz crystals are found in a few localities, while chert and hornstone are quite common. Fluorite has been observed in at least three localities, and the quite rare mineral ceruleolactite occurs at the Glen Loch ore mines, in the Little Chester valley.

Associated Rocks

In the valley regions the prevailing rock is limestone, which varies in composition from nearly pure carbonate to a form with a high percentage of silica, and from dolomite to a variety nearly free from magnesia. In Nittany valley, in Center county, the upper portion of the limestone is highly calcareous, while the lower portion is very arenaceous, in fact grading in several places into a silicious sandstone, which reaches a thickness of 300 or 400 feet.

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*Second Pennsylvania Geol. Survey, D, p. 26.

White Clay

Intercalated with both the Ordovician and the Cambrian limestones and associated with the Cambrian quartzites underneath the limestones are beds of hydromica slates, which on exposure weather into clays. These clays are frequently parti-colored from the iron oxide stains, but in many localities are almost entirely free from iron and are nearly snow white. These white and parti-colored clays are very intimately associated with the iron ores, in a great many banks the ores resting on or against a deposit of the clay.

Exposures of the white clay are most numerous in the South Mountain area, in Cumberland county, where it occurs in nearly every one of the ore pits designated on figure 5. Similar deposits occur at various horizons in the limestone valleys, but most abundantly near the base of the Cambrian portion of the limestones. In Lehigh and Berks counties there are several ore pits exposing white clay in the limestones near the top of the Trenton, not far from the contact with the overlying shales. In Nittany valley the clays occur in the proximity of the sandstone beds in what probably corresponds to the Calciferous division, as Calciferous fossils were found in what is to all appearances the same horizon.

The evidence that the white clays are the weathered products of the hydromica slates is (1) the intimate gradation of the clay into the slightly weathered slates, which is shown clearly in clay pits at Latimore, York county, and in the ore pit at Hensingerville (see figure 4); (2) the occurrence in the clay of several ore pits of fragments of the undecomposed slate, and (3) the occurrence in many of the clay exposures of numerous fragments of white quartzite, similar in appearance to the interlaminated thin quartzite lenses which are nearly always present in the slate exposures.

In the Lower Cambrian horizon below the limestones are beds of sandstones, quartzites, conglomerates, and talcose slates. There are many diabase dikes cutting through the sedimentary rocks in different localities, but they bear no direct relation to the ore deposits.

Mode of Occurrence

The ores occur for the most part in fragments of varying sizes, commingled with the residual material resting upon limestones, slates, or sandstones. The residual material consists of clay, sand, and chert, with occasional fragments of sandstone, limestone, and shale. The relative proportion of the ore to the residual material is quite variable, in most of the pits a good average being one part of ore by bulk to five of residue. Locally the yield may reach 75 per cent or more. In very few localities can the ore be handled with profit if it forms less than 15 per cent of the entire mass. The diffused iron oxide is almost universally distributed through the residuary mass over all the limestone areas, portions only of the white clay deposits being free from it. Isolated ore fragments are pretty widely met, only comparatively small areas being entirely free from them; but areas in which the ore fragments occur in commercial quantities (that is, forming 15 per cent or more of the mass), while numerous, are limited in extent and form a very small proportion of the entire limestone and slate belt. A few of the largest ore banks, such as the Scotia bank in the Nittany valley, extend over an area of 100 acres or more; but many are limited to less than half an acre, and some are only a few yards in extent.

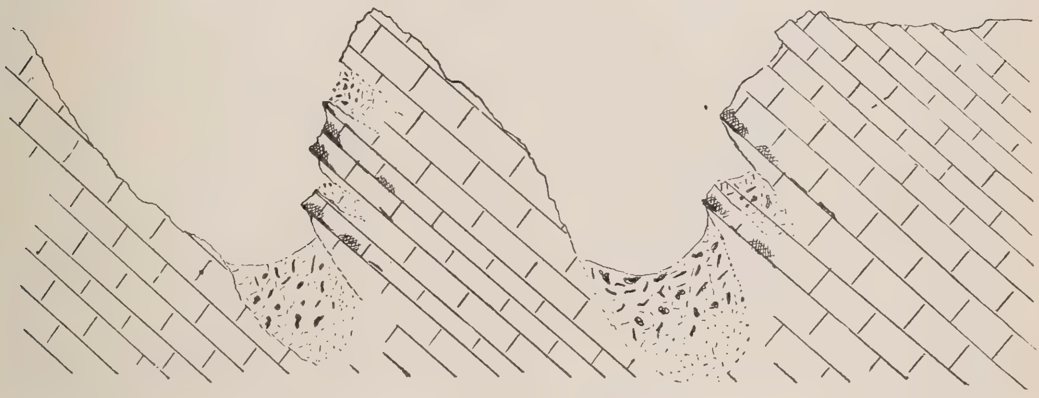

FIGURE 2.—*Section at Pennsylvania Furnace Ore Bank.*

Showing occurrence of ore in the bedding and joint seams of the limestone.

In the limestone areas the ores occur generally in pockets or solution cavities in the limestone, which are quite irregular in outline and quite variable in depth (see plate 50, figure 2, and also text figure 2). The atmospheric waters have attacked the basset edges of the limestones, which have yielded much more rapidly in some places than in others. The clay, chert, sand, and iron oxide—the insoluble materials—collect in these solution cavities. In a few places the ore may be seen in position in the seams of the limestone, one of the best illustrations of which is in the Pennsylvania Furnace ore bank, in the Nittany valley (see figure 2), where it occurs in both the bedding and the joint seams, but most abundantly in the latter, which may be due in part to the fact that they are better exposed to view than the others. The ore deposit is on the argillaceous and silicious matter in the seam, and not in direct contact with the limestone, which is a sandy, silicious variety, leaving on the weathered surface, in places, a silicious skeleton or framework sometimes coated with ore. The ore is laminated parallel with the walls of the seams. As the limestone decays, the thin sheets of ore break down and mingle with the residual clay, furnishing the commercial ores. The ore which occurs in place in the seams in the limestone and the fragments visible in the residual clay are all thin and fragile so far as observed; but the bottoms of the ore pockets are concealed by debris, and it is possible that the sheets become thicker at greater depths, as is frequently reported by the workmen.

In the slate areas the ore with the other residua rests upon a mass of clay, in many cases white clay, stained locally by iron oxides. As the slates from which the clays are derived are interstratified with the limestones, there can be no very sharp distinction drawn between the ore deposits on the limestone and those on the clay. In many districts the greater part of the ore deposits are found on the white clay. So common is this occurrence that it may be stated as a general rule that in areas where the clays occur they are associated with the ore deposits, but where the clays are absent the ores occur in the eroded cavities in the limestone, as described above. One general distinction can be made between the purely limestone deposits and the limestone-clay deposits. The latter are generally richer at the bottom in direct contact with the white clay, while the former may be as rich at the top as at the bottom. Solid bodies of ore are spoken of by the miners in many places, but I have never seen any such more than a few hundred pounds in weight that were not mixed with foreign materials. Professor Prime, who examined many of the Lehigh Valley mines when they were in operation, says:* "At times a thick, solid bank of ore is found in a mine. This is, however, rare, and continues but a short distance." Lesley † mentions the occurrence of such bodies, but his statements appear to be based on reports by mine superintendents, rather than on his own observations.

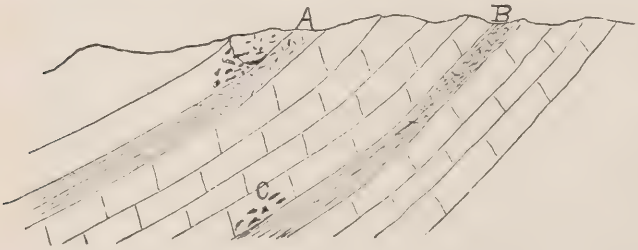

Figure 3.—*Ideal Section Illustrating Possible Mode of Accumulating Iron Ore underneath the Clay by Process of Segregation and Leaching.*

Occasionally ore bodies are found in or underneath the white clay.

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* Second Geol. Survey of Pennsylvania, Report D D, p. 50.

† Proc. Am. Phil. Soc., vol. xiv.

This may be caused by a segregation of the ores in underlying limestones, and the subsequent leaching out of the intervening rock permits the upper clay to rest on the ore, as shown in figure 3. Should the second accumulation rest on clay the final result is an ore body inclosed in the clay. In some instances the cause of the ore being beneath the clay is an overturn or an overthrust of the strata. Structural relations support this view at several localities on Mountain creek, in Cumberland county. Sometimes it is simply irregularity in weathering.

While usually the ore deposits rest on the white clay, occasionally they occur in it, and in one place, Hensingerville, the ore is found impregnating the hydromica slates from which the clays are derived, thus showing how the ore may get into the clay. In the joint and lamination seams of the slates the ore occurs in thin flakes, which resemble those mentioned in the limestone at Pennsylvania Furnace, except that they are smaller and more numerous, just as the seams of the slate are more numerous and closer together. The exposure is on the south wall of an old ore pit (see figure 4), and the interlamination of the ore extends at least to the depth of the pit, 60 feet below the surface, and presumably deeper, as the pit opening, extending more than 100 feet north, was formed by the removal of the clay for the ore contained therein, and which must in part, at least, have come from slates underlying those exposed. When the workmen making the excavation came in contact with the but partially disintegrated slates on the south face, the mining was no longer profitable and operations ceased. A shaft 50 feet back from the quarry face shows a similar occurrence of the ore flakes in the seams of the slate to the bottom of the shaft, 15 feet below the surface. In this mine the bombshell or nodular ore was quite abundant, forming concentric shells in the slate and the resultant clay (see figure 1).

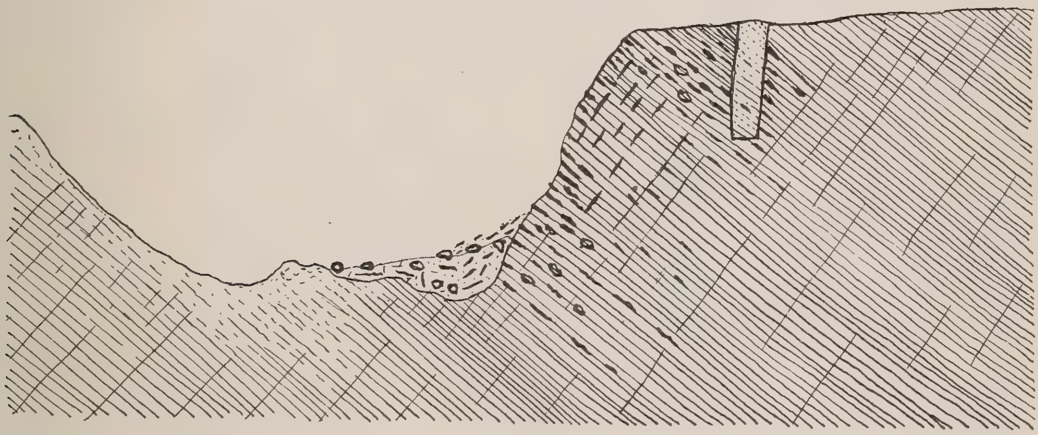

FIGURE 4.—*Cross-section of Ore Bank at Hensingerville, Pennsylvania.*

Illustrating accumulations of ore in the hydromica slates.

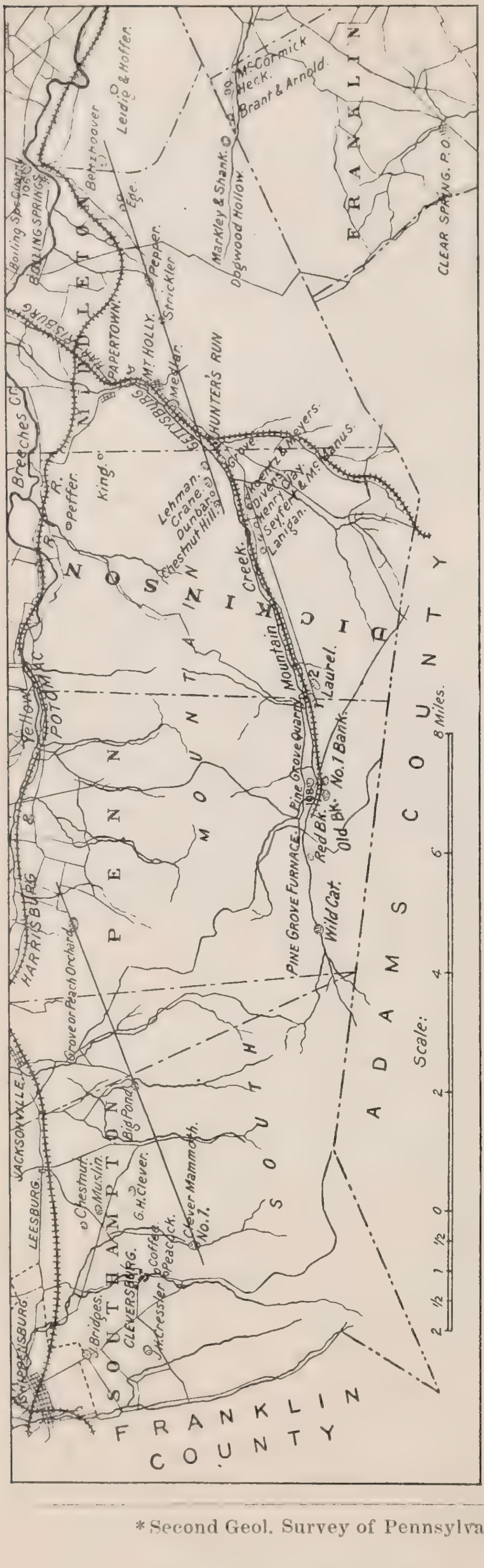

FIGURE 5.—*Map of South Mountain Region, Cumberland County, Pennsylvania.*

Showing the alignment of many of the ore banks.

Some of the ore pits are shallow, striking the limestone *in situ* at a depth of 8 or 10 feet. Many of them range in depth from 50 to 90 feet, but the ore frequently extends to a much greater depth. The expense of elevating the materials and of keeping out the water generally causes a cessation of work at about 90 feet below the surface. The actual depth of the ore deposit in a few places is surprisingly great. At the Lehman mine, in Cumberland county, a hole was drilled 435 feet below the bottom of the ore pit. The report of the boring gave 340 feet of ore (presumably ore and clay), 40 feet of blue clay, 30 feet of white clay, and 25 feet of "mountain clay."* A record of a well-boring at Lambourne, in the Nittany valley, gives 300 feet of ore and clay, 450 feet of white sand, 16 feet of limestone, a total depth of 766 feet, or 750 feet to the solid limestone rock, yet limestone may be seen outcropping on all sides of this well less than half a mile distant. It is difficult to account for the excessive deep disintegration of the rocks at this point.

Prime and Lesley emphasize the statement that the ore occurs in regular belts along definite horizons. Rogers* says the occurrence of the ores is empirical, and bears no very close relation to the underlying rocks, except in the Kishacoquillas valley, where he finds that the ores occur over the anticlinal axes in the fissures produced by the flexure of the limestones. The parallelism is shown to the best advantage where the slate belts are most pronounced, as the slate or its residual clay determines the location of the ore bodies. The accompanying map of the South Mountain area in Cumberland county illustrates this feature to better advantage than any other area; yet, while it may be noticed that most of the pits occur along well defined belts, quite a number can not be so arranged (see figure 5). These pits lie in the slate area, where there is some intercalary limestone, but the main limestone belt of the valley lies north of the area shown on the map. In the limestone valley areas the parallelism is so subordinate that it has little significance, as shown on the accompanying map of a portion of the Lehigh County ore region (see figure 6).

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* Second Geol. Survey of Pennsylvania, An. Rept., 1886, pt. iv, p. 1462.

In the Cumberland County region the prospectors recognize the alignment of the ore deposits and take advantage of it in seeking new bodies of ore, but this can not be followed very successfully in the more purely limestone areas.

In portions of Nittany valley a heavy bed of sandstone in the axis of the anticline restricts the ores to a comparatively narrow belt on either side of the sand ridge, and concentrates them to a considerable extent along the contact of the sandstone and limestone, but elsewhere in the valley ore pits have been opened at many different horizons, ranging from the oldest limestones exposed to the overlying Utica shales.

The conclusion of the writer is that the ore deposits may occur at any horizon in the limestones, but since a great many of the larger deposits occur on beds of sand or clay, residual from sandstones and slates, and since these intercalated beds are generally of considerable extent, there is in such places a consequent alignment of the deposits, corresponding to the strike of the rocks and sufficiently pronounced in a region of slate beds to be useful in following up the ore bodies, but in the limestones free from intercalated slates or sandstones there is very little regularity about the occurrence of the ore.

ORIGINAL SOURCE OF THE IRON

The discussion of the origin of the limonite ores may be conveniently divided into two heads—the original source of the iron and the mode of its concentration.

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* Geology of Pennsylvania, 1858, vol. 1, p. 479.

The possible sources of the iron in the Cambro-Ordovician limonite ores are (1) the Lower Cambrian slates, where it occurs both as pyrite and silicate; (2) the Cambro-Ordovician limestones and included slates, where it exists as diffused carbonate, sulphide, and silicate; (3) the overlying Ordovician and Silurian shales and sandstones, where it occurs as carbonate, sulphide, and hydrous oxide.

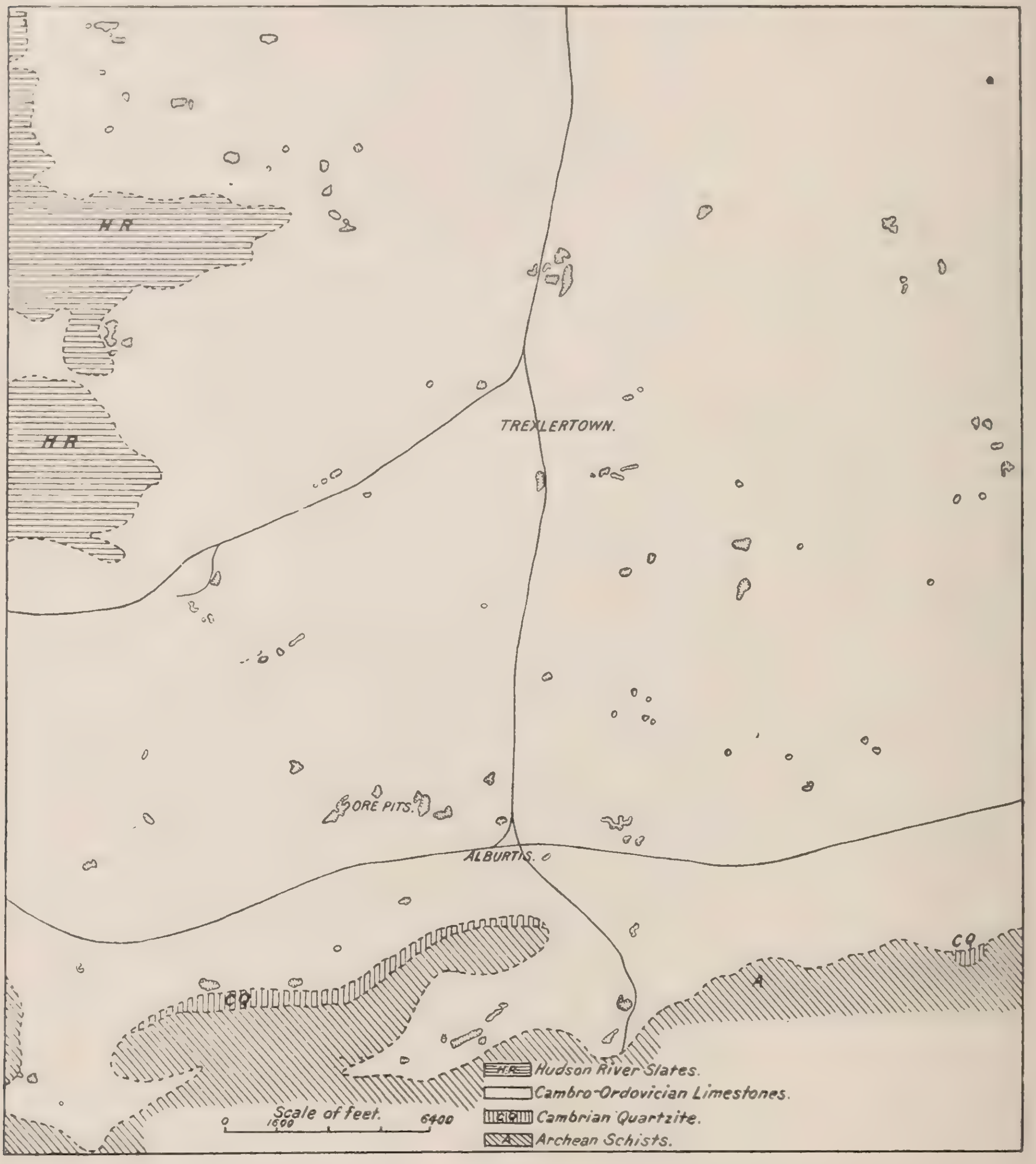

Figure 6.—*Map of Portion of Great Valley Region, western Part of Lehigh County, Pennsylvania.* Showing distribution of the limonite ore pits. Reduced from map in Report D D, Second Geological Survey of Pennsylvania.

It is well known that all strata contain more or less iron, and those in and bordering the limestone valleys of Pennsylvania are no exceptions.

Each of them has furnished a portion of the iron for the ore deposits, but not necessarily all in the same ratio or even in proportion to the amount of iron which they contain. The manner in which erosion removes material has much to do with what becomes of the different constituents. The erosion of sandstones, clays, and slates is largely mechanical, and the included minerals would in large measure be carried away as sediment along with the rock material. Limestone, however, is largely removed in solution, and the insoluble constituents accumulate in the residue. This is one of the reasons why the writer thinks that much of the iron ore of the limestone valleys has been derived from the Cambro-Ordovician limestones on which they occur.

The reasons for attributing the source of some of the iron to the overlying sandstones and slates are (1) that these rocks contain iron and overlie the rocks on which the ores occur; (2) in some places meteoric waters pass through or over these rocks into the limestones, and as the waters contain organic acids, they would naturally dissolve some of the iron; (3) in some places seepage from the shales at the top of the limestone has been observed to be impregnated with iron. The reasons for thinking that this source of supply is not large in comparison with that from the limestones are (1) that the shales and slates are not readily permeable and serve to turn the water from the limestone where topographic conditions make it possible; (2) that in general the most extensive ore deposits are near the base of the limestones; (3) and that the erosion of the shales is largely mechanical and rapid and most of the iron contained in them would be carried away as sediment.

That the iron in the ore deposits on the lower horizons has been derived in part from the Lower Cambrian slates seems probable, in view of the fact that the slates in some places are impregnated with iron pyrites, the weathered surface often showing many minute cubical cavities from which the pyrite has been leached out. The slates intercalated in the limestones are likewise a probable source of iron, as analyses of samples from three different localities show the following percentages of ferric oxide: 0.91, 5.06, and 2.40. There is a possibility, however, that part of the iron in the slates analyzed may have been carried in from the overlying limestone. That all of the iron is not derived from the hydromica slates is evident from the fact that extensive deposits of ore occur in the Ordovician limestones in localities where the slates do not occur, except in horizons below the ore deposits. The slates, as noted elsewhere, occur in the Ordovician limestones in Lehigh county, but they are not present in Nittany valley, except near the base of the series, in the oldest rocks exposed in the valley. Furthermore, where the slates do occur, the ores are in nearly all cases on top of them and not underneath. Unless we suppose the iron to be carried upward by ascending waters, which is hardly probable, there appears to be no reasonable way in which the ores in the upper horizons could be derived from slates in the lower ones.

The reasons for thinking that the Cambro-Ordovician limestone series is the principal source of the iron in the ore deposits are: (1) the great number of the deposits in the limestone area and their wide distribution over all the different limestone horizons, from the top to the bottom of the series; (2) the intimate commingling of the ores with the residual clay and chert fragments from the dissolution of the limestones; (3) the almost universal occurrence of the deposits on and not under the intercalary beds of clay; (4) the manner of erosion of the limestone, which is wholly by solution, thus offering the most favorable condition for the preservation and the accumulation of the ores; (5) the limestones contain iron—in small quantities, it is true, but I think sufficiently large. The accompanying analyses of limestones from different localities show an average content of one and a quarter per cent of iron carbonate and sulphide. A thickness of 6,000 feet of limestone, which is present in the Nittany valley, would represent 40 feet of iron ore, which is probably in excess of any deposit in the valley. However, this is subject to a number of qualifications which seriously modify any computations in this line.

On the one hand it can not be assumed (*a*) that all the iron in the limestone is changed to ore proper, as often a considerable portion of it remains in the residual clay in the form of yellow ocher, or (*b*) that all the ore remains in the residual material, as part of it, although a comparatively small part, is carried away as sediment in the streams; I say a small part, because the streams in the limestone area are few in number, small in size, and carry very little sediment; (*c*) many of the ore deposits are not at the bottom, but some of them are near the top of the limestone.

On the other hand, it is to be noted (*a*) that the limestones are in nearly all cases highly inclined, sometimes almost vertical, and the thickness of limestone eroded over any given ore deposit may be much greater than that represented by a section normal to the bedding at that point. This is illustrated in figure 7, where *A O* would represent the actual thickness of limestone over the position of the ore deposit *O* in normal position, but *O B* represents the actual thickness eroded in the inclined position. The fact that part of the limestone was probably eroded during the process of folding would not materially alter the result, as the residual materials would not be greatly shifted thereby. (*b*) There would be a lateral as well as a vertical segregation of the iron. It has been stated that the ore occurs in pockets in eroded depressions in the limestone. These are in many instances at the bottom of former sink-holes at the surface, and, as shown by the present conditions, these sink-holes may collect the drainage from areas many acres in extent. Both the surface and the subterranean drainage would naturally transport the iron both while in solution and later in the lump form toward the sink or cavity. Further evidence in support of this view is the customary mode of occurrence of the ore in the erosion cavities which are separated by more or less barren areas.

While the percentage of iron in the limestone is small, it forms a comparatively high ratio of the insoluble residue, averaging 24 per cent for the whole 16 analyses. Considering the proportional loss of iron to be no greater than that of the other materials, this would apparently furnish a sufficient supply of iron for all the ore deposits.

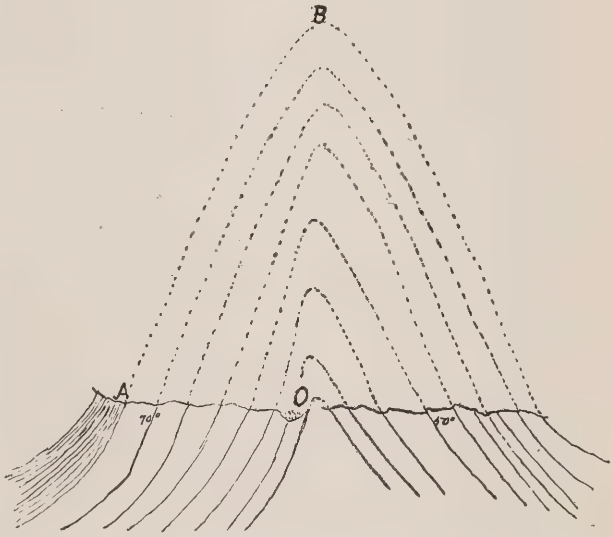

FIGURE 7.—*Cross-section of Anticline in Nittany Valley, Pennsylvania.*

Analyses of the limestones (see page 494) indicate that the iron occurs both as the carbonate and as the sulphide, with the carbonate in excess in all cases. The analyses, while not many in number, are from several quite widely separated localities and presumably represent fairly well the relative amounts of the two compounds, although there may be local enrichments of iron not shown by the analyses. As mentioned under associated minerals, both the carbonate and the pyrite occur in limited quantities in a few places, associated with the limonites, but they are evidently secondary forms, and cannot be considered as indicating in any way the original form of the iron in the limestone. No pyrite crystals have been observed in any of the many limestone exposures examined by the writer. The intercalated hydromica slates in many places contain considerable iron, apparently in the form of silicate, which Bischof states is soluble in carbonate waters, and part of which is presumably added to the supply from the limestone.

The conclusion is that some of the iron in the limonite ore deposits is derived from the overlying Ordovician shales and some from the underlying Cambrian slates, but the chief source is the diffused iron carbonate, *Analyses of Cambro-Ordovician Limestones*

	Lehigh county.							Cumberland county.				Franklin county.		Huntingdon county.		
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
$FeCO_3$	1.035	1.450	.538	1.398	1.305	1.188	4.060	.653	1.537	1.552	4.420	.665	1.420	.80	.50	1.31
FeS_2..........	.030	.611	.268	.105	.320	.238	.174	.076	.186	.102	.011	.011	....	......	......	......
Insoluble residue.....	8.980	10.750	8.400	11.670	10.980	7.850	......	4.040	3.570	5.747	2.310	4.090	2.130	3.84	4.33	18.05
Al_2O_3.........	.070	.140	.065	.860	.300	....	6.09	......	.110	.280	.083	.222	....	.54	42	3.81
$CaCO_3$.......	49.316	51.558	86.036	70.750	56.220	83.632	53.875	57.087	68.225	66.220	72.32	51.743	92.079	59.44	51.82	72.67
$MgCO_3$........	40.463	35.216	4.594	15 256	31.201	5.462	25.494	28.314	27.110	26.860	20.590	43.436	4.420	35.19	42.52	3.98
Carbonaceous matter......	.250	.210	.420	.120	.120	.835	....	.130	.010	.050	......	......	......	......	......	......
Phosphorus...	.006	.018	.016	.019	.005	.026	.089	.007	....	.013	.047	.013	....	......	......	......

Numbers 7 and 16 are from Mineral Resources, U. S. Geological Survey, 1889–1890.
All the others are from Reports M_2 and M_3 of the Second Pennsylvania Geological Survey.
All the analyses except numbers 7 and 16 were made by Doctor Genth.

sulphide, and silicate, mostly the first, in the Ordovician and Cambrian limestones and the intercalated slates.

MODE OF ACCUMULATION OF THE IRON

The form of the ore fragments and the mode of their occurrence, as explained above, necessitate the conclusion that the ores are secondary or derived products. It yet remains to show the manner in which the iron oxide was collected from its diffused condition in the original rock into the deposits of commercial ore in which it now occurs. To bring this about, (1) solution, (2) transportation, and (3) precipitation are necessary. The atmospheric waters are the agents which have produced the change.

Oxygenated waters acting on the pyrite would take it into solution by oxidizing the sulphur into sulphuric acid, part of which combines with the iron as ferrous sulphate and part remains free or combines with any other base that may be present. The reaction is $FeS_2 + 7O + H_2O = FeSO_4 + H_2SO_4$. The H_2SO_4 would readily combine with any lime or magnesia carbonate present, forming the corresponding sulphates. The $FeSO_4$ will rapidly oxidize to basic ferric sulphates and finally to hydroxide.

The iron carbonate is soluble in all acidulated waters—in sulphuric acid as the sulphate, in carbonic acid as the bicarbonate, in organic acids as the corresponding organic salt. As one or more of these acids is nearly always present in meteoric waters near the surface, the solution of any iron carbonate necessarily follows a contact with them. In the presence of oxygen and moisture both the sulphide and carbonate change readily to ferric oxide, which change may take place in the original position of the iron, and later it may be again taken into solution and be added to the iron supply for the ore deposits.

The ferric oxide is much less soluble than the ferrous oxide, and is the most stable form of iron in nature. It is not appreciably soluble in carbonic acid or ordinarily as ferric oxide in the organic acids, although Bischof* and Julien† state that ferric oxide is soluble in apocrenic acid in the presence of ammonia. The organic acids, however, are active reducing agents, and change the ferric oxide to ferrous, in which form it is soluble, as above stated, in any of the acids. Illustrations of this action may be seen at almost any point where roots penetrate yellow clay. A zone of white or light colored clay from which the iron has been leached may be seen surrounding the decayed or decaying roots.

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* Elements of Chem. and Phys. Geology.

† Proc. Amer. Assoc. Adv. Sci., 1879, vol. 28, p. 401.

Where there is sufficient vegetable growth, all of the iron may be extracted, as in some of the underclays of the Coal Measures.

The organic acids are an important factor in the transference of the iron, as well as in its solution. In fact, so important and direct is their action that many geologists raise the question whether every great accumulation of iron ore does not necessarily imply the presence of organic matter. The ferrous salts are unstable in the presence of oxygen, and hence would not remain long in solution in meteoric waters unless some reducing agent were present. The organic acids have such a strong affinity for oxygen that as long as they are present they prevent the oxidation of the iron to the insoluble oxide, or, what amounts to the same thing, speedily reduce it to the soluble form again.

The meteoric waters, charged with organic and other acids, reduce, dissolve, and carry away the iron in solution. The next step is its precipitation, which is in most cases from the bicarbonate solution, since carbonic acid is the final stage of all the organic acids. The precipitation may be caused by (1) relief of pressure, (2) oxidation, (3) desiccation or concentration, and (4) neutralization or chemical reaction by another salt in solution, or by replacement of another base in the solid, or it may be a combination of two or more of these causes. The iron may be precipitated as the hydroxide, as the carbonate, or as one of the organic salts, but, in whatever form, it is only a question of time until it is brought to the stable form of the hydroxide. The precipitation from the sulphate solution may be by oxidation alone or, what is more probable, oxidation and neutralization combined.

The precipitation may take place quite remote from the original position or it may be quite near or even at that point, as is the case in the pseudomorphs of limonite after siderite and pyrite. In the limestone regions it is thought that the iron is not carried far in solution, because, as the waters become saturated with lime, which is more soluble than the iron, the latter would be precipitated. A large part of the iron is probably deposited in the upper or cavernous portion of the limestones.

Part of the iron is deposited in cavities and caverns in the limestone, as already indicated in the description of the ore forms. The concentric layers of fibrous ore, lining some of the nodular masses, clearly indicate deposition in a cavity, as do the iron oxide stalactites. The loose masses of pipe ore indicate pretty conclusively that they were formed in caverns, The nodules that were formed by the iron oxide, coating rock fragments. were formed probably in caverns or in the residual material. The brecciated ores were formed by the deposition of the iron in a mass of loose rock material ; it may have been in caverns, on the surface, or in the residual material. The sheet ore is, without doubt, formed in seams in the limestone and in the slate, as already shown (see figures 2 and 4). It is broken up and mixed with the other residua by the leaching away of the surrounding and underlying limestone and by the whole mass sinking down to a lower level. An important horizon for the deposition as well as the accumulation of the ores is at the contact of the limestone with an underlying insoluble layer, such as slate or sandstone.

Some of the ores are oxidized concretionary masses which have formed in the rock before it was disintegrated (see figure 1). I did not see any nodular ore masses in position in the limestones of the area under discussion; but the nodular ore fragments are frequent in the residual material, and they evidently were formed either in the limestones or in the intercalary clay layers.

The accumulation of the clay-ore masses is aided in part by the inequalities in the dissolution of the limestone, and in part by the occurrence of insoluble beds of clay or sand intercalated in the limestones. Thus there is a tendency, in the first place, as previously stated, for the ores to collect in caverns, and as their roofs break through or are dissolved by the waters, there is a further tendency for the loose materials immediately surrounding the cavity to work into it by gravitation, and the ores, being heavier than the clay, tend to work deeper, toward the bottom of the opening.

The interstratified clay and sand beds aid in the concentration of the ores by forming an insoluble layer on which the ores may collect from the overlying limestone. Thus a bed of clay, as shown in figure 3, may serve as a final repository for all the ores of the overlying limestone bed, whether it be 200 or 2,000 feet thick. There will also be a lateral movement down the inclined bed of clay, slate, or sandstone. Thus, in figure 3, for example, all the ore from the triangular space *A C B* may be collected in a comparatively small area at *C*. Should there be a cross-folding in the other direction, at right angles to the main fold, so as to form a synclinal trough down the slope *B C*, the concentration will be all the greater. We have here an explanation of the rich ore deposits on the clay beds in the Great Valley area and on the sand deposits in Nittany valley. It is possible for the concentration to be going on at two or more levels at the same time. Thus in the figure cited the concentration may have begun at *C*, while it is still going on at *A*; but eventually the upper deposit will be brought to the lower one by the leaching out of the intervening limestone. If the clay seam at *A* is comparatively thin, it may lose its identity in the mixture of other materials before reaching the lower level.

If this explanation be the true one, the newest ore, as a rule, will be at the bottom, and the ore deposits will increase in size by additions below. There is probably no appreciable addition of ore at the top of the mass or any marked enrichment except on the steep slopes, where there is little or no vegetation, and the rivulets wash away part of the imbedding clay into the surface streams.

There is probably to some extent a segregation of the iron oxide into lump ore in the residual material, but I suspect that any such segregation is largely confined to the margin and bottom of the mass, as the body of the clay-ore mass is not readily permeable to water.

The conclusion is that the diffused iron of the limestones and slates is segregated into nodular masses, pipes, and sheets of ore in large measure in the limestone or in the seams and cavities in the same and in or on the top of the slates previous to the final dissolution of these rocks. The leaching away of the limestone leaves the ores scattered through the residual material. The segregating of the oxide may be continued in the residual clays, especially around the margins, but less actively than in the original beds.

SUMMARY

Extensive deposits of limonite ores occur in the residual clays on the Ordovician and Cambrian limestones and slates in the Great valley, Nittany, Kishacoquillas, and Chester valleys, in central and eastern Pennsylvania. The ores are hydrous ferric oxides, consisting largely of limonite, associated with which are local occurrences of turgite and goethite and very limited quantities of hematite, magnetite, pyrite, and siderite. The ores are associated with manganese ores, wavellite, quartz, chert, and fluorite. They occur as pipes, shells, nodular and brecciated masses, and irregular fragments mingled with more or less residual clay and sand lying in irregular pocket-like deposits of varying sizes in cavities on the limestones or on beds of white clay or sandstone.

The original source of the iron is primarily the Cambro-Ordovician limestones and slates, with smaller quantities from the overlying Ordovician and possibly Silurian strata and the underlying slates and quartzites. The iron occurs in these strata as carbonate, sulphide, and silicate, the first being probably the most common.

The segregation of the diffused iron into the ore lumps is brought about by the meteoric waters. The higher oxide is reduced by the organic acids. The ferrous oxide is taken into solution by the organic and carbonic acids, possibly sulphuric acid in some measure. The iron is precipitated from the solution in part as the hydroxide, in part as the carbonate, which is later oxidized. Some of the ores have been concretionary segregations, probably as the carbonate, in the original rock, and subsequently oxidized in the residual material. Some are formed in seams and cavities on and in the beds of slate, limestone, and sandstone. The deposits increase in size largely by the segregation of the oxide into the scattered nodular and flake-like masses in the underlying limestones, which are subsequently leached out, leaving the ores in residual material similar to that in the overlying clay-ore mass which settles down upon it. The ore nodules and flakes may form at any point in the limestone, but the most favorable horizon for their concentration is at or near the contact of the limestone with an underlying bed of slate or sandstone, which forms a collecting place for the ores. The intercalated slates weather to a white clay, which thus forms the repository for many of the ore masses.

LITERATURE ON THE LIMONITE ORES

The following bibliography gives a brief summary of what has been published about the origin of the limonite ores in question. In general, reference is made only to the literature bearing directly on the origin of the limestone valley limonites, but a few specific references on other points are mentioned :*

BENTON, E. R.: Tenth Census, volume xv, 1880.

The ores are pseudomorphs after broken limestone by filling the cracks and thickening the films, changing from solid limestone above to irregular shell ore at the bottom.

BISCHOF, GUSTAV: Elements of Chemical and Physical Geology, volume 2.

Hydrated oxide of iron decomposes silicate of alumina. From a solution of bicarbonate of iron and bicarbonate of lime a current of atmospheric air causes all the iron to be precipitated as hydrated peroxide before the lime begins to separate.

DANA, JAMES D.: American Journal of Science, third series, 1884, volume 28, page 398.

The limonite ore beds of the eastern United States result from the oxidation *in situ* chiefly of ferriferous limestone. The ferriferous limestones were formed in interior basins or marshes by iron bicarbonate or salt of an organic acid washed down from the land over areas of calcareous deposits. These ore beds, although superficial, can not be said to be modern. They have probably been in progress ever since the land emerged from the ocean.

DAVIS, O. W., JR.: The iron ores of Maine, Journal United States Association of Charcoal Iron Workers, 1886, volume 1, page 66.

The ores in the vicinity of Katahdin, Maine, which occur in Silurian clay slates, have been formed by the decomposition and oxidation of pyrites.

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*A full bibliography on iron ores is published in Bulletin number x of the Minnesota Geological Survey.

D'INVILLIERS, E. V.: Second Pennsylvania Geological Survey, Report T, page 136.

The pipe ores are caused by (1) the decomposition of iron pyrite in the limestone ore slate bands, which after oxidation as sulphate filled interstices in the limestone and "changed into peroxide by contact with vegetable matter or other organic substances," or (2) the production of ferrous carbonate by reaction between ferrous sulphate and calcium carbonate and afterward changed to limonite by oxidation and hydration. The wash or lump hematites are wash deposits caught in vast caverns of irregular shape.

EWING, A. L.: Second Pennsylvania Geological Survey, Report T, page 408.

The original condition was as ferrous salts, in most cases carbonate. It is probable that portions of the iron have been dissolved, transported, deposited, and oxidized during the process of rock decay, yet the facts would indicate that the greater part is due to oxidation *in situ*.

FONTAINE, W. M.: Quoted by E. C. Pechin in Proceedings of the Iron and Steel Institute, October, 1890.

The ores are formed by the concentrating action of concretionary forces that have collected the once diffused iron into masses, which have a more or less distinctly concretionary structure, or which form beds of nodular ore or crusts lying in inclosing clay.

FRAZER, PERIFER, JR.: Second Pennsylvania Geological Survey, Report C, page 142.

The pyrites of the hydromica slates furnish ferrous sulphate and free sulphuric acid which reacts on the soda in the slates, producing sodium sulphate, which in turn reacts on the lime bicarbonate, giving soda carbonate and lime sulphate. The sodium bicarbonates react on the ferrous and ferric sulphates, forming hydrous oxide from the latter and hydroferrous carbonate from the former, which is farther oxidized to ferric hydrate. This is one of many suggestions.

HARDEN, J. W.: Transactions of the American Institute of Mining Engineers, 1873, volume 1, page 136.

The ore is the residue of the decomposition of the slates and limestones.

HUNT, T. S.: Second Geological Survey of Pennsylvania, Report E, pages 202–204; Transactions of the American Institute of Mining Engineers, volume xi, page 244.

The ores are formed by the oxidization *in situ* of deposits of carbonate of iron, and in some places pyrite interstratified in the more or less argillaceous slates now changed to clay.

JACKSON, R. M. S.: Nittany Valley Iron Ores, 1838–'39.

The ores are deposited *in situ* freed from the limestone during the process of erosion and disintegration.

JULIEN, A. A.: Proceedings of the American Association for the Advancement of Science, 1879, volume 28, page 401.

Whatever the source of the iron oxide may have been, whether pyrite or other ferruginous minerals, the action of humus acids may be suspected. They probably served for its transport and as the erosive agents in the excavation of the numerous limestone caverns. If it should be established that the iron was first deposited as carbonate, its solution and decomposition were probably accomplished by these acids previous to its oxidation and hydration.

KENDALL, J. D.: The Iron Ores of Great Britain and Ireland, London, 1893.

The limonite ores are oxidized carbonates which are formed by replacement of limestone. The direct source of the iron may have been the clay deposits, but it originally came from volcanic rocks. In the replacement of limestone by iron carbonate there would be a diminution of volume of about 18 per cent. There would be a corresponding loss of 18 per cent in the change from carbonate to limonite.

KIMBALL, JAMES P.: American Journal of Science, September, 1891, and American Geologist, December, 1891.

The iron in solution replaces the lime carbonate in the limestones and is subsequently oxidized.

LEONHARD, ——: Jahrbuch fur Mineralogie, 1845, page 14.

Describes the formation of ferric hydrate stalactites now going on in a mine near cape Cornwall. Stalactites 18 inches long and an inch in diameter have been formed since the mine was abandoned. It seems probable that these were formed by waters carrying iron carbonate in solution.

LESLEY, J. P.: Proceedings of the American Philosophical Society, volume ix, page 463.

The ore is the residue of the Silurian slates and sandy limestones. The geologist can procure specimens of every stage, from limestone which refused to disintegrate and the iron-lime sandstone with the disintegration and crystallization begun to the perfect ball and pot ore.

Proceedings of the American Philosophical Society, volume xiv, page 19.

The original source of the iron is the limestone, from which it is set free during erosion. Three theories, each applicable to different kinds of ores, are: 1, that part of the ores which occupied caverns, fissures, and sink-holes now lie in pockets; 2, the deposits which show gravel and rolled ore and a commingled mass of ore sand and clay are surface washes; 3, there are interstratified beds of brown hematite still in their original position, descending between layers of sandstone and limestone to undetermined depths.

Final Report of the Second Pennsylvania Geological Survey, page 364.

It is quite possible that all the Great Valley limonites are cavern deposits of very recent date, derived from the decomposition of a series of damourite lime shales belonging to various horizons in the Chazy and Calciferous magnesian limestones.

LYMAN, BENJAMIN SMITH: Proceedings of the American Association for the Advancement of Science, 1867, volume 16, page 115.

The ore was deposited in regular beds at the same time as the other rocks. They have been broken into fragments at their outcrop, and the fragments have accumulated in quantities varying according to the lay of the ground.

MERRILL, F. J. H.: Bulletin of the New York State Museum, volume 4, number 19, page 221.

The existence of the carbonate in the deeper parts of some of the mines and their interstratification with the limestones is suggestive of the origin of the limonites by the decomposition of the ferruginous beds, through oxidation and the agency of carbonated waters.

NEWBERRY, J. S.: Engineering and Mining Journal, 1881, volume 31, page 299.

They are the accumulation of iron carried in the surface drainage, deposited by aeration and oxidation. The iron came from the surface drainage of rock and soil, the decomposition of pyritous rocks, and a residual from ferriferous limestones. The formation has evidently been going on from the Cretaceous age to the present.

PENROSE, R. A. F., JR.: Journal of Geology, 1894, volume ii, page 304.

Many of the iron ore deposits in the Cambrian and Lower Silurian can be clearly shown to be due to a superficial replacement of limestone, or even of more silicious rocks like shales, by iron dissolved from ferruginous rocks in the neighborhood. In such cases the iron in the original rock has been dissolved and carried off in carbonated surface water and reprecipitated in the other rocks, all these stages being directly due to surface influences.

PORTER, JOHN B.: Transactions of the American Institute of Mining Engineers, volume 15, page 177.

The ores are formed from oxidized pyrite, which occurs either in masses or disseminated through the older rocks. The saying, "No ore is under where the water stands" is a key to the great cause in the formation of limonite.

PRIME, F., JR.: American Journal of Science, third series, 1875, volume 9, page 438; Transactions of the American Institute of Mining Engineers, 1875, volume 3, page 410.

The brown hematites were probably formed by the oxidation of iron pyrites, but not *in situ*. It is uncertain whether the pyrite was disseminated through the limestone or whether there was a bed especially rich in pyrite. The oxidation of the pyrite produced protosulphate of iron, which reacts on the limestones and the carbonate of lime and magnesia in the damourite slates, producing iron carbonate, which is deposited, and lime sulphate, which is carried off in solution.

Second Pennsylvania Geological Survey, Report D, pages 53, 59.

The pipe ore has evidently formed by deposition from solution by the oxidation of some ferrous salt, probably the carbonate. "The ore must then have been formed either from the decomposition of ferrous salts *in situ*—that is, ferrous silicates or carbonate—from the solution of the ferrous carbonate in the limestone and its redeposition in the damourite slates or from the same reaction of the ferrous sulphate formed by the oxidation of pyrite." The potash of the damourite slates must have exerted an important agency in the formation of the ores in their present position and condition.

ROGERS, H. W.: Geology of Pennsylvania, 1858, volume i, page 183; volume ii, page 721.

Much of the iron (of the ores of the Primal series) was originally pyrite in minute crystals in certain layers of the slate.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 11, PP. 503-510 AUGUST 10, 1900

CONTACT METAMORPHISM OF A BASIC IGNEOUS ROCK

BY ULYSSES SHERMAN GRANT

(Presented before the Society December 30, 1899)

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INTRODUCTION

In volumes 4 and 5 of the Final Report of the Geological and Natural History Survey of Minnesota, and in some of the annual reports of the same survey, mention is frequently made of certain peculiar crystalline rocks which occur along the northern edge of the great gabbro mass of northeastern Minnesota. The rocks in question furnish one of the most interesting cases of metamorphism of a series of rocks of varied lithology by the contact effect of a basic igneous mass. It is the object of this paper to present in outline an account of the phenomena here seen.

OUTLINE OF LOCAL GEOLOGY

The triangular area of Minnesota lying north of lake Superior is underlain by rocks of pre-Cambrian age. In general these are disposed in belts, which trend east-northeast and west-southwest. Those of greatest age are toward the north, so that in traversing this district from the Canadian boundary south to lake Superior one passes over rocks of the following ages in the order named: Archean, Lower Huronian (or Keewatin), Upper Huronian (or Animikie), and Keweenawan. These series are separated by unconformities. The first two series frequently have been closely folded, while the last two dip toward the south-southeast at angles of from 5 to 20 degrees.

The Archean consists in the main of greenstones and of granites, more or less schistose. The former were originally basic igneous rocks, and in most cases they have not as yet been carefully separated from the overlying Keewatin, which also contains masses of greenstone. Granites, intrusive into the Keewatin, also occur.

The Lower Huronian (or Keewatin) is composed of a variety of sedimentary and igneous rocks, the most numerous of which are conglomerates, graywackes, jaspilytes, greenstones, and slates and schists of several kinds.

The Upper Huronian (or Animikie) rests unconformably upon the older rocks, and along the contact with the gabbro has not been subjected to the intense dynamic action which has folded and sheared these older rocks. The dip of the Animikie averages about 10 degrees toward the south or south-southeast, but where it disappears under the gabbro the dip is commonly much steeper. The Animikie is separable into four members, in ascending order, as follows:

1. The quartzite member.
2. The iron-bearing member, in which the important iron deposits of the Mesabi range occur.
3. The black-slate member, which is composed essentially of black, carbonaceous, frequently very fissile, slates.
4. The graywacke-slate member, consisting of black to gray slates and fine grained graywackes, with some flinty slates and slaty quartzites.

The lower member is lacking in the district where the gabbro occurs.

The Keweenawan consists at its base of a mass of gabbro, which is frequently associated with more acid rocks of somewhat later date. Above these is a series of basic igneous rocks, with the uppermost parts of which some sandstones and conglomerates are intercalated.

KEWEENAWAN GABBRO

The gabbro occupies a roughly crescentic area which reaches lake Superior at its western end, but elsewhere is several miles north of this body of water. The crescent is some 125 miles in length, and the total surface area underlain by the gabbro is approximately 1,000 square miles. It is therefore a mass of considerable size.

The gabbro is a coarse grained aggregate of plagioclase, which is near labradorite; augite, which is often diallagic; olivine, and magnetite, with occasionally hypersthene, biotite, hornblende, and minor accessory minerals. In general, the mass is of fairly uniform composition. Variations, however, take place mainly in three directions: First, by increase of feldspar the rock becomes an anorthosite; second, by increase of feldspar and olivine a forellenstein is formed; third, by increase of magnetite masses of titaniferous magnetic iron ore originate. Along its northern limit the gabbro, while at times assuming a finer grain, usually preserves its distinctly coarse grain and granular texture to its contact with the underlying rocks.*

Although this large mass of rock has been regarded as the earliest flow or series of flows of Keweenawan time, there has been a recent trend of opinion toward the conclusion that the gabbro is not of extrusive, but more probably of intrusive nature, and that it has the form of a laccolite. There is, so far as known, no separation of this enormous mass into distinct beds or flows similar to the other flows of Keweenawan age, nor have any of the characteristic textures of surface rocks been reported from the gabbro proper. It must be said, however, that the southern or upper side of this mass has not been studied in detail. Moreover, the marked metamorphosing effects which the gabbro has had on the underlying rocks along its northern border—effects described below—also point to the non-extrusive character of the mass.

Contact Metamorphism produced by the Gabbro

GENERAL CHARACTER OF THE METAMORPHISM

This metamorphism is very noticeable, and consists of a partial or a complete recrystallization of the adjacent rocks. Complete recrystallization is the rule near the contact, and in places this extends 500 feet from the contact. A partial recrystallization is at times noticeable for a distance of a quarter of a mile or more from the present surface limits of the gabbro.

In northwestern Cook county, Minnesota, the gabbro is in contact with the uppermost or graywacke-slate member of the Animikie. In going westward this igneous mass cuts across the strike of the Animikie, touching the black-slate and the iron-bearing members, then strikes the Keewatin, and finally reaches the Archean. In the rocks of each of these series certain characteristic contact phenomena can be seen. In Lake county the gabbro, except for isolated patches of the iron-bearing member of the Animikie, is in contact with still older rocks, and in eastern Saint Louis county the Animikie again emerges from beneath the gabbro.*

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* The petrography of the gabbro has been described by W. S. Bayley (Journal of Geology, 1893, vol. 1, pp. 688-716), and by N. H. Winchell and the writer (Geological and Natural History Survey of Minnesota, Final Report, vol. 5, in press).

GRAYWACKE-SLATE MEMBER OF THE ANIMIKIE

Where the gabbro is in contact with the uppermost member of the Animikie there is a marked contact zone, in which the sedimentary rocks are much hardened and have a massive aspect, appearing at a distance like igneous rock, while close to the gabbro they are completely recrystallized. Near the contact the more silicious strata have been turned into completely crystallized quartzites. The less pure silicious rocks consist of granitic aggregates of quartz, feldspar, biotite, and muscovite in varying proportions, with occasionally cordierite. It is to be noted that the minerals common to the gabbro, especially pyroxene and olivine, which are so abundant in the metamorphosed rocks of the iron-bearing member of the Animikie and of the Archean, described below, are absent from these silicious rocks at the gabbro contact. A short distance from the contact the recrystallization becomes less complete, although biotite and muscovite have been developed.

BLACK-SLATE MEMBER OF THE ANIMIKIE

The known exposures do not show any contacts of the gabbro on the next lower or black-slate member of the Animikie, but in a few places somewhat removed from the contact and in the immediate vicinity of sills of diabase cordierite has been developed in these slates. A fragment referred to these black carbonaceous slates and included in the gabbro is now a completely crystallized aggregate of quartz, graphite, and biotite, with large plates of beautifully pleochroic hypersthene, which incloses the other minerals in a poikilitic manner.

IRON-BEARING MEMBER OF THE ANIMIKIE

It is in the next lower or iron-bearing member of the Animikie that the most interesting contact phenomena are exhibited. This member is the one in which, farther west, the immense hematite deposits of the Mesabi range occur. The original rock is regarded as a glauconitic greensand, in which there is more or less iron carbonate. This rock has been altered to a quartz-magnetite-amphibole slate, the amphibole being in the form of actinolite, grünerite, cummingtonite, and hornblende. This quartz-magnetite-amphibole slate, commonly known in the Lake Superior region as actinolite schist, has been profoundly changed by the gabbro, and the resulting rock is a coarse grained aggregate of quartz, magnetite, olivine (which is frequently fayalite), hypersthene, augite-hornblende, and occasionally grünerite, and cummingtonite. These rocks, like the rocks from which they are derived, are beautifully banded, the separate bands being composed of quartz, or of magnetite, or of silicates, or of a mixture of any two or more of the minerals. The texture of the different bands is granitoid as a rule, but in some cases one mineral, notably the hypersthene, is developed into large plates, which include the other minerals in a poikilitic manner. These contact rocks, which on account of the abundance of magnetite and olivine are sometimes called the olivinitic iron ores, are so peculiar that attention has been called to them by several geologists. As they have been referred either to the Lower Huronian or to the Upper Huronian (or Animikie) or to the gabbro (Keweenawan) itself by different geologists, it seems best to present briefly the evidence proving their real age.* This seems best also because, on account of the abnormal mineral composition of these rocks, there may be some hesitancy about accepting their original sedimentary nature.

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* Cf. Geol. and Nat. Hist. Survey of Minn., Final Rept., 1899, vol. 4, pls. 67, 68, 69.

The facts which show the Animikie age of the rocks in question may be stated as follows:

1. The outcrops, while not absolutely continuous, are of sufficient frequency to allow the gradual tracing of the quartz-magnetite-amphibole slates along their strike into these highly crystalline rocks.
2. In following these outcrops a gradation in crystalline and mineral nature can be traced from the slates to the rocks in question.
3. Certain structural features of the region, the details of which can not be given here, are most readily explained by assuming the Animikie age of the olivinitic iron ores.
4. The rocks underlying and those overlying the olivinitic iron ores are the same as those underlying and overlying the less altered slates—that is, the stratigraphic positions of the two are similar.
5. The rapid alternations of bands of different compositions in the two rocks are exactly similar.
6. The anomalous mineral composition of these highly crystalline rocks can be explained as the direct result of the mineral composition of the Animikie rocks from which they were derived. The peculiar mineral character consists in the presence of so many and such large amounts of minerals which are not commonly found in metamorphosed sediments, but which are characteristic of basic igneous rocks—that is,

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* Of the geologists who have studied the rocks in question the writer understands that J. M. Clements, A. H. Elftman, C. K. Leith, C. R. Van Hise, and H. V. Winchell agree with the interpretation here given, namely, that these rocks are parts of the iron-bearing member of the Animikie metamorphosed by the gabbro. N. H. Winchell, while formerly holding this interpretation, now regards these rocks as of Keewatin age. W. S. Bayley has described them, or at least large parts of them, as peripheral phases of the gabbro.

olivine, augite, and hypersthene. To present this point more definitely, it can be stated, first, that from the quartz and magnetite of the slates can be formed the quartz and magnetite of the metamorphic rocks; second, that from the actinolite and hornblende of the slates can be formed the augite and the hornblende of the metamorphic rocks; third, that from the grünerite ($FeSiO_3$) can be formed the fayalite (Fe_2SiO_4); fourth, that from the cummingtonite ($[MgFe]SiO_3$) can be formed the olivine ($[MgFe]_2SiO_4$) and the hypersthene ($[FeMg]SiO_3$). It is thus clear that the materials necessary for the formation of the minerals of the metamorphic rocks were all present in the original quartz-magnetite-amphibole slates. It is not the intention of the writer to state that there was no transfer of material from the gabbro during this metamorphism. This may have taken place, but it is not necessary to assume even a limited transfer, for the materials requisite for the manufacture of the minerals of the metamorphosed rocks already existed in the iron-bearing slates.

Turning now to the reasons for regarding these peculiar metamorphic rocks as not facies of the gabbro, it may be stated:

1. That the rocks in question contain no feldspar, which is the most abundant mineral in the gabbro.
2. That quartz is abundant in the metamorphic rocks, while it is absent in the normal gabbro. If these rocks were facies of the gabbro we would have the anomalous feature of much free quartz in an ultra-basic rock.
3. That the magnetite of the olivinitic iron ores is not titaniferous, while the magnetite masses of the gabbro are highly titaniferous, and the magnetite of the ordinary gabbro is also titaniferous.
4. That where the two rocks come into contact there is no gradation between them, but a sharp and definite separation can be made. Moreover, at the contact the gabbro is finer grained than away from this line. The same sharp separation can be made where sills from the gabbro lie in the iron-bearing rocks, and here the fineness of grain of the sills at the contact is very marked.
5. That there are nowhere in the gabbro such intimate laminations and bandings as in the rocks in question.

These iron-bearing rocks have suffered much more extensive recrystallization than other strata with which the gabbro has come in contact. The exact reason for this is not clear, but probably the peculiar composition of these rocks in part conditioned the result.

THE KEEWATIN

Where the gabbro is in contact with strata of Lower Huronian age there has been the usual recrystallization, but as these strata are diverse in mineral composition the resulting metamorphic rocks vary greatly. A very prominent feature of these altered rocks is the presence of much biotite, while in the intermediate vicinity of the contact hypersthene is developed frequently in poikilitic plates.

THE ARCHEAN

Along the northern border of the gabbro the Archean is represented by two types of rocks, granites and greenstones. Contact metamorphism in the first of these has not been noted; in fact, it may be questioned whether the gabbro induced any marked changes in these acid rocks; but in the other type, the greenstones, a series of changes has taken place which has produced rocks of a peculiar nature. Originally the greenstones here considered consisted of gabbros, diabases, diorites, or the finer grained extrusive and fragmental equivalents of these rocks. They have been subjected to many vicissitudes, and in their present composition they are aggregates of hornblende, plagioclase, kaolinite, epidote, quartz, and minor alteration products. The metamorphism induced by the gabbro has been of a nature which has tended to reproduce the original minerals of these greenstones. The result is in some cases quite similar to a fine grained gabbro. In fact, some of these metamorphosed greenstones have been described as parts of the great gabbro mass, while, on the other hand, certain fine grained and granulitic phases of the gabbro have been referred to these changed greenstones. The resemblance between the two rocks is quite marked on surfaces which have been exposed to the weather, both forming yellow granular masses, which crumble readily under the hammer. There is, however, a difference between these apparently similar rocks of diverse origin. and a judicial combination of field evidence and microscopical study will commonly enable one to decide to which category the rock of a given outcrop belongs. The granulitic gabbros are confined within (that is, to the south of) the northern boundary line of the gabbro mass. This line can be, and in fact for a considerable distance has been, carefully located. The metamorphosed greenstones are without (that is, to the north of) this boundary, and, moreover, they can usually be traced directly into the less altered greenstones, the zone in which the complete recrystallization has taken place being commonly a comparatively narrow one. In thin sections the granulitic gabbros present a typically granular texture and the grains are very uniform in size. Hornblende is not common, and olivine and hypersthene are at times found.

In the metamorphosed greenstones the texture is not so typically granular, and the grains vary considerably in size, although many of them have the approximately circular outlines which are so noticeable in the granulitic gabbros. Moreover, in the metamorphosed greenstones there is usually much hornblende and sometimes a little quartz, and it is only in close proximity to the gabbro that augite and hypersthene are found in any considerable amounts. Olivine has not been noted, and quite frequently the hornblende and hypersthene are in poikilitic plates.

SUMMARY

In conclusion, it may be stated that the great mass of gabbro at the base of the Keweenawan in Minnesota has features which indicate its intrusive rather than its extrusive nature; that one of the most important of these features is the marked contact zone along the lower or northern side of this mass; that in this zone a complete recrystallization of the strata has been effected, at times for a distance of a few hundred feet from the igneous rock, with less pronounced effects extending for a quarter of a mile or more; that the rocks resulting from the contact metamorphism of the iron-bearing member of the Animikie are peculiarly rich in minerals of the basic rocks—that is, in augite, hypersthene, and olivine; that the materials for these minerals were present in the quartz-magnetite-amphibole slates of the Animikie, and consequently that it is not necessary to consider these minerals as derived from the gabbro; and that the contact effects on some altered basic igneous rocks have been to reproduce the original mineral characters of these rocks and to produce textures partially similar to true igneous rocks.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 11, PP. 511-651, PLS. 51-58 OCTOBER 31, 1900

PROCEEDINGS OF THE TWELFTH ANNUAL MEETING, HELD AT WASHINGTON, D. C., DECEMBER 27, 28, 29, AND 30, 1899, INCLUDING PROCEEDINGS OF FIRST ANNUAL MEETING OF THE CORDILLERAN SECTION, HELD AT SAN FRANCISCO DECEMBER 29 AND 30, 1899

HERMAN LE ROY FAIRCHILD, *Secretary*

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SESSION OF WEDNESDAY, DECEMBER 27

The twelfth winter meeting of the Society was called to order at 10 o'clock in the Lecture hall of Columbian University, where all the sessions were held. The President, Professor Benjamin K. Emerson, occupied the chair throughout the meeting.

Mr G. K. Gilbert, in behalf of the Fellows resident in Washington and the scientific societies of the city, made a brief address of welcome, to which the President responded.

The first item of administrative business was the report of the Council, including the annual reports of the officers, which the Secretary submitted in print, without reading, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Twelfth Annual Meeting Assembled:

During the past year the Council has held its stated meetings in connection with Society meetings, the attendance at Columbus being one less than a quorum. The affairs of the Society are in good condition, and the Council has no special business or recommendations to present. The details of the past year's administration will be found in the following reports of the officers:

SECRETARY'S REPORT

To the Council of the Geological Society of America:

Meetings.—The records of the Eleventh Annual Meeting, held at New York, December, 1898, and the Eleventh Summer Meeting, held at Columbus, Ohio, in August of this year, are not yet printed, but will doubtless be distributed in a few weeks. The Summer Meeting occupied one day of the time of Section E, American Association for the Advancement of Science.

Membership.—During the year death has removed four eminent Fellows, two of them being past Presidents of the Society. Othniel C. Marsh died March 18; Oliver Marcy, March 19; Edward Orton, October 16, and J. William Dawson, November 19.

The candidates elected at the New York and Columbus meetings all qualified except one, which adds 13 names to the list. Four resignations have been accepted and three names erased for non-payment, which leaves 239 names upon the membership list at this date. Six Fellows are delinquent for 1898, and 8 candidates are now awaiting election.

Official year—Date of reports.—The By-Laws make the fiscal year of the Society close November 30. For some years the Secretary's report of expenditures has been made to correspond in time with the Treasurer's report, but it was not convenient to close the account of Bulletin distribution and receipts on November 30. This year, however, owing to delay in printing of volume 10, it would not be possible to make a full report upon the volume even by the end of the calendar year, and hence the opportunity is used to make the Secretary's financial report coincide in time with the Treasurer's. If the Council approves of this, the financial statements in future reports of the Secretary will be to November 30 of each year.

Distribution of Bulletin.—On account of delay in the printing of the latter part of volume 10, the figures given in the column covering the distribution of that volume are incomplete, but will be supplied for the permanent record.

DISTRIBUTION OF BULLETIN FROM THE SECRETARY'S OFFICE DURING THE YEARS 1891–1899

Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Vol. 8.	Vol. 9.	Vol. 10.
Distributed to Fellows	......	......	209	214	214	223	222	231	234	233
Donated to "exchanges"	91	91	89	89	89	87	85	85	84	85
Sold to libraries	92	92	94	90	87	92	85	82	81	73
Sold to Fellows	25	19	13	9	6	4	3	2	1	.....
Sent to Fellows, deficient	2	1	1	......	......	......	......	1	2	.....
Donated	4	4	3	3	3	3	2	2	1	1
Bound for offices and library	3	3	3	3	3	3	3	3	3	3
Volumes in reserve	51	300	342 (?)	346 (?)	337 (?)	92 (?)	104 (?)	99 (?)	101 (?)	105 (?)
Complete vols. received	264	506	750 (?)	750	734	500 (?)	500 (?)	500 (?)	500 (?)	500 (?)

Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.	Vol. 6.	Vol. 7.	Vol. 8.	Vol. 9.	Vol. 10.
Sent to Fellows, deficient.	50	141	46	43	28	17	15	14	17	......
Sent to libraries, deficient	3	8	5	6	3	1	4	8	3	1
Sold to Fellows	19	22	11	13	19	2	2	3	3	......
Sold to public	15	18	17	16	8	13	6	7	6	2
Donated	3	3	3	3	2	......	......	......	......	......

Subscriptions.—Including the annual orders from dealers for the Bulletin by brochures, there are now 73 subscribers. Three sets of the Bulletin were sold as the result of advertising at the beginning of the year.

Bulletin sales.—The receipts from the Bulletin since the last report are $504.41.

RECEIPTS FROM SALE OF BULLETIN FROM DECEMBER 31, 1898, TO NOVEMBER 30, 1899

By Sale of Complete Volumes

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.
From Fellows	$4 50	$4 50	$4 00	$3 50	$4 00
From libraries	15 00	15 00	15 00	15 00	20 00
Total for 1899	19 50	19 50	19 00	18 50	24 00
By last report (1898)	562 10	541 00	518 50	480 00	453 00
Total to date	$581 60	$560 50	$537 50	$498 50	$477 00

	Vol. 6.	Vol. 7.	Vol. 8.	Vol. 9.	Vol. 10.	Total.
From Fellows	$4 00	$4 00	$8 00	$4 00	....	$40 50
From libraries	15 00	15 75	20 00	225 00	$75 00	430 75
Total for 1899	19 00	19 75	28 00	229 00	75 00	471 25
By last report (1898)	471 00	422 00	394 00	170 00	40 00	4,051 60
Total to date	$490 00	$441 75	$422 00	$399 00	$115 00	$4,522 85

By Sale of Brochures

	Vol. 1.	Vol. 2.	Vol. 3.	Vol. 4.	Vol. 5.
From Fellows	....	....	....	....	....
From public	$1 90	$1 95	....	$0 55	....
Total for 1899	1 90	1 95	....	0 55	....
By last report (1898)	27 20	21 25	37 75	11 60	6 85
Total to date	$29 10	$23 20	$37 75	$12 15	$6 85

	Vol. 6.	Vol. 7.	Vol. 8.	Vol. 9.	Vol. 10.	Total.
From Fellows	$2 00	....	....	$0 91	....	$2 91
From public	1 00	....	$0 60	3 45	$0 80	10 25
Total for 1899	3 00	....	0 60	4 36	0 80	13 16
By last report (1898)	8 25	8 45	4 55	0 60	....	126 50
Total to date	$11 25	$8 45	$5 15	$4 96	$0 80	$139 66

Grand total	$4,662 51
Received for volume 11 in advance	20 00
Total receipts to date	$4,682 51
Charged and uncollected	31 00
Total sales of Bulletin to date	$4,713 51

Exchanges.—No changes have been made in the list, which will be found at the end of volume 10.

Expenses.—The following table shows the cost of administration for the fiscal year:

EXPENDITURE OF SECRETARY'S OFFICE FOR THE FISCAL YEAR, NOVEMBER 30, 1898, TO NOVEMBER 30, 1899

Account of Administration

Postage	$26 51	
Expressage	2 99	
Printing (including stationery and records)	146 79	
Meetings (not included in printing)	36 25	
Total		$212 54

Account of Bulletin

Postage	$92 50	
Expressage and freight	31 95	
Wrapping material and labels	21 53	
Printing	5 75	
Collection of checks	3 30	
Total		$155 03
Total expenditure for year		$367 57

Respectfully submitted.

H. L. Fairchild,
Secretary.

Rochester, N. Y., *December 10, 1899.*

Treasurer's Report

To the Council of the Geological Society of America:

In submitting the annual statement of receipts and disbursements for the year ending December 1, 1899, the following items of general interest are also given:

Two (2) members were dropped from the roll during the year for non-payment of dues; two (2) are delinquent for two years, and twenty-eight (28) for the present year, while eight (8) others, a much larger number than usual, have made their Fellowship sure by commuting for life.

The names of these Fellows so commuting by the cash payment of $100 each are Frank R. Van Horn, Theodore G. White, Myron L. Fuller, A. R. Crook, N. F. Drake, A. C. Spencer, William Libbey, and Cleveland Abbe, Jr.

Statement of Receipts and Expenditures.

RECEIPTS.

Balance in the treasury November 30, 1898			$1,389 85
Fellowship fees 1897 (5)	$50 00		
" " 1898 (27)	270 00		
" " 1899 (164)	1,640 00		
		$1,960 00	
Initiation fees (13)		130 00	
Life commutation fees (8)		800 00	
Interest on investments:			
Tioga Township, Kansas, bonds	$70 00		
Cosmos Club bonds	85 00		
Tunnelton, Kingwood and Fairchance Railroad bonds	18 00		
Texas Pacific Railroad bonds	100 00		
Deposits with Security Trust Co, Rochester, N. Y.	60 28		
		333 28	
Sales of publications by Secretary, deposited with Security Trust Co., Rochester, N. Y.		549 41	
			$3,772 69
Total amount of receipts			$5,162 54

EXPENDITURES.

Administration, library, and distribution of Bulletin — Secretary's office:			
Administration	$216 04		
Distribution of Bulletin	162 34		
Allowance (for traveling and clerical expenses)	300 00		
	$678 38		
Treasurer's office	22 30		
Librarian's office	7 85		
		$708 53	
Maps and photographs:			
George P. Merrill account		47 20	
Publication of Bulletin:			
Printing	$939 83		
Engraving	276 96		
Editorial expenses (allowance for personal and office expenses)	160 00		
		1,376 79	
Total amount of expenditures			$2,132 52
Balance in treasury December 1, 1899			$3,030 02

No permanent investments have been made during the year, owing to the high price of all desirable securities, the Texas Pacific first mortgage bonds, which were purchased last year at less than par, being now quoted at 115; hence the surplus funds have been kept with the Security Trust Company of Rochester, New York, where the Society realizes 4 per cent on monthly balances, which is quite as much interest as could be secured from first-class securities at present prices.

The Treasurer will continue this policy until there is some change in the security market, unless instructed otherwise by Council.

The interest item of $60.28 shows the income from this source, which added to $273, the amount realized from the invested fund of $5,000, makes $333.28, a very good addition to the Society's resources.

The detailed financial operations of the treasury may be read in the table on the preceding page.

This balance for the year, $3,030.02, is much larger than usual because of the delay in the publication of volume 10, and also because so many Fellows have paid life commutations, which, for reasons already given, have not yet been expended for permanent investments.

Respectfully submitted.

I. C. White,
Morgantown, West Va., *December 22, 1899.* *Treasurer.*

Editor's Report

To the Council of the Geological Society of America:

It is to be regretted that the final material for volume 10 was not forthcoming in time to enable the Editor to complete the Bulletin and present his report to the Council at the usual date in December. This report, which is made at each winter meeting, is necessarily based on the *published* volume. Owing to the delay in placing material in the Editor's hands, volume 10 was not disposed of until January 19, 1900, three weeks after the Council meeting at which reports are submitted, hence it was impossible to have the report ready at the proper time. A little promptness on the part of some of the publishing members would have avoided this undesirable result. The Bulletin could have been issued well within the publication year, and the persistent effort being made by the officers of the Society to secure prompt printing of papers, approved as it is by the Society as a whole, ought to have the hearty cooperation of individual members.

Volume 10 consists of 534 pages of text and xii pages of preliminary matter and is illustrated with 54 plates and 83 text figures. In pages it compares favorably with any volume issued except numbers 2 and 5, while in illustrations, both plate and text, it surpasses them all. In cost it was as economic as is consistent with the high standard of excellence adopted by the Society.

The Editor takes pleasure in announcing that arrangements have been made for the preparation of the index for the first 10 volumes of the Society's publications. It will be printed as a separate brochure and issued some time during the coming summer—probably just after the completion of volume 11.

Although exact classification is not attempted, the following comparative table presents reasonably good analyses of the contents of volumes 7, 8, 9, and 10:

Divisions.	*Vol. 7. Pages.*	*Vol. 8. Pages.*	*Vol. 9. Pages.*	*Vol. 10. Pages.*
Areal geology	38	34	2	35
Dynamic geology	3	24	85	24
Economic geology	4	14	16	28
Glacial geology	105	98	138	96
Historical	..	..	..	16
Memoirs of deceased members	28	8	12	27
Official matter	56	69	54	72
Paleontology	123	58	64	68
Petrology	40	43	44	59
Physiographic geology	53	5	..	37
Relation of geology to pedagogy	12	..	..	..
Rock decomposition	74	26	17	9
Stratigraphic geology	21	67	28	62
Terminology	1	..	..	1
Total	558	446	460	534

The cost of each of the ten volumes thus far issued by the Society is as follows:

	Vol. 1. (pp. 593; pls. 13)	Vol. 2. (pp. 662; pls. 23)	Vol. 3. (pp. 541; pls. 10)	Vol. 4. (pp. 458; pls. 10)	Vol. 5. (pp. 665: pls. 21)
Letter-press	$1,473 77	$1,992 52	$1,535 59	$1,286 39	$1,887 21
Illustrations	291 85	463 65	383 35	173 25	178 40
	$1,765 62	$2,456 17	$1,918 94	$1,459 64	$2,065 61

	Vol. 6. (pp. 528; pls. 27)	Vol 7. (pp. 558; pls. 24)	Vol. 8. (pp. 446; pls. 51)	Vol. 9. (pp. 460; pls. 29)	Vol. 10. (pp. 534; pls. 54)
Letter-press	$1,341 93	$1,463 60	$1,262 22	$1,176 64	$1,399 82
Illustrations	221 62	200 24	317 76	231 91	441 99
	$1,563 55*	$1,663 84*	$1,579 98	$1,408 55	$1,841 81

* The actual cost to the Society was $77.50 less for volume 6, and $90.80 less for volume 7, those amounts being paid by authors for illustrations and correction charges.

Respectfully submitted.

JOSEPH STANLEY-BROWN,
Editor.

WASHINGTON, D. C., *January 20, 1900.*

LIBRARIAN'S REPORT

To the Council of the Geological Society of America:

The list of additions to the library for the year ending March 1, 1899, was made out and forwarded to the Secretary during that month.

The Case Library building adjoins the Cleveland post-office. The land on which it stands is desired for the new post-office building authorized by the last Congress. Condemnation proceedings have passed through the court and the award is made. Acceptance of the award by the government is probable, though not yet announced officially, nor is it known whether the library trustees will appeal. The library has been placed temporarily in an unfortunate position, since no steps providing for its future housing could be taken until it was known whether they would be necessary or not. Possibly the library may be for a time temporarily without quarters. One moving and possibly two are in prospect. As there is so little call for books on the part of the Fellows of the Society, the Librarian seems the only individual likely to suffer inconvenience.

Some 160 volumes have been bound during the past year, and another year will see completed all the binding that was in arrears at the time of the present Librarian's appointment.

The expenses of the library during the past year, up to September 5, are as follows:

To express	$2 00
" printing	1 45
" postage and postal cards	4 40
Total	$7 85

Respectfully submitted.

H. P. CUSHING,
Librarian.

CLEVELAND, OHIO, *December 11, 1899.*

On motion of the Secretary, it was voted to defer consideration of the report until the following day.

As the Auditing Committee, to examine the accounts of the Treasurer, the Society elected Arthur Keith and Edmund O. Hovey.

ELECTION OF OFFICERS

The result of the balloting for officers for 1900, as canvassed by the Council, was announced by the President and declared elected as follows:

President:

GEORGE M. DAWSON, Ottawa, Ont.

First Vice-President:

Charles D. Walcott, Washington, D. C.

Second Vice-President:

N. H. Winchell, Minneapolis, Minn.

Secretary:

H. L. Fairchild, Rochester, N. Y.

Treasurer:

I. C. White, Morgantown, W. Va.

Editor:

J. Stanley-Brown, Washington, D. C.

Librarian:

H. P. Cushing, Cleveland, Ohio.

Councillors:

W. B. Clark, Baltimore, Md.
A. C. Lawson, Berkeley, Cal.

ELECTION OF FELLOWS

The result of the balloting for Fellows, as canvassed by the Council, was announced by the President, and the following persons were declared elected Fellows of the Society:

Irving Prescott Bishop, 109 Norwood avenue, Buffalo, New York. Professor of Natural Science, State Normal and Training School.

Emilio Böse, Ph. D., Calle del Paseo Nuevo no. 2, Mexico, D. F. Geologist of the Instituto Geologico de Mexico.

Arthur Starr Eakle, B. S., Ph. D., University Museum, Cambridge, Massachusetts. Instructor in Mineralogy and Petrography, Harvard University.

August Frederick Foerste, A. B., A. M., Ph. D., 417 Grand avenue, Dayton, Ohio. Teacher of Science.

John Flesher Newsom, A. B., A. M., Stanford University, California. Associate Professor of Metallurgy and Mining, Stanford University.

Samuel Lewis Penfield, Ph. B., M. A., New Haven, Connecticut. Professor of Mineralogy, Sheffield Scientific School of Yale University.

Charles Henry Richardson, A. B., A. M., Ph. D., Hanover, New Hampshire. Instructor in Chemistry and Mineralogy, Dartmouth College.

Arthur Brown Willmott, B. A., B. Sc., M. A., Toronto, Canada. Professor of Geology and Chemistry, McMaster University.

The following memoirs of deceased Fellows were read :

*MEMOIR OF OTHNIEL CHARLES MARSH**

BY CHARLES E. BEECHER

Among the leading men of science in America, Professor Othniel Charles Marsh was unquestionably one of the best known and had one of the strongest personalities. The world-wide reputation he enjoyed, however, is not altogether attributable to the particular department of research in which he stood without a peer, for, added to his attainments in vertebrate paleontology, he possessed an unusual number of mental qualifications in other lines, as well as marked personal characteristics, which made him known and felt where his science could never reach. His fame will undoubtedly rest on his work among the fossil vertebrates. Nevertheless, his energy and attainments in other directions were sufficient to have made for him a permanent record.

The nearness of the perspective at the present time renders it difficult properly to individualize and accord the true rank to the many important discoveries Marsh has made. He brought forth in such rapid succession so many astonishing things that the unexpected became the rule. The science of vertebrate paleontology could not assimilate new material so fast, and it will be years before the true significance and bearing of much that he has done will be understood. The constant stream of vertebrate riches which from 1868 to 1899 flowed into the Yale University Museum from the Rocky Mountain region had a similar bewildering effect on Marsh, for it was impossible for him to do more than seize on what appealed to him as the most salient. The work of the hour was to him of prime importance, whether it was for the determination of a new order of mammals or a new cusp on a tooth. Still, he seems to have had a just conception of relative values, for it will be found that he plucked the most luscious plums from the paleontological tree, and left chiefly the smaller or unripe and imperfect fruit untouched.

Another element in his success was seen in the improvement he made in the methods of collecting, preserving, and developing vertebrate fossils, so that even forms long known only from fragmentary remains were represented in his collections by almost complete specimens, presenting nearly the same degree of novelty shown in forms actually new.

As a collector, Marsh was seen at his best, and the collections he amassed during his forty-five years and more of activity in this direction form a lasting monument to his perseverance and foresight. A person with means and inclination may be supposed to have the necessary qualities for accomplishing his aims, whether they are first editions, autographs, or fossils, but had Marsh possessed no further qualifications than these, the results of his collecting would fall far short of what he really attained. He not only had the means and the inclination, but entered every field of acquisition with the dominating ambition to obtain everything there was in it, and leave not a single scrap behind. Every avenue of approach was made use of, and cost was often a secondary consideration. The nine-tenths, when attained, were only an additional stimulus for securing the remaining one-tenth. Of course, this ideal of completeness was often impossible of accomplishment, and yet it served to bring to the Yale University Museum collections which are unique from their richness and extent.

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*Abridged, with alterations, from the account published in the American Journal of Science, fourth series, vol. vii, June, 1899. This memoir was not presented at the meeting, but is inserted here in its place.

In making an estimate of his character, it must not be forgotten that he developed wholly without the influence of family and home ties, which in most men profoundly mark their mature life. Self-reliance is probably the strongest trait fostered by the absence of immediate family connections. This Marsh possessed to an extraordinary degree, and it naturally led to a self-centering of his life and ambitions. Out of it came, also, an absence of the complete exchange of confidence which normally exists between intimate friends. Even where perfect confidence existed, he seldom revealed more about any particular matter than seemed to him necessary or than the circumstances really demanded. As a friend, he was kind, loyal, and generous. As a patron of science, he has seldom been equaled. Honest work in any department appealed to him strongly, and he was ever ready with aid and counsel, even at the expense of a personal sacrifice. His disposition was a most happy one, and he was always keenly appreciative of the humorous and ludicrous and fond of relating amusing experiences and anecdotes. The sunny side of his nature was nearly always uppermost, and the consideration of subjects of the greatest gravity was enlivened by constant sparkles of wit from his exhaustless store.

He was normally restive under restraint, and met all opposition with power and fearlessness. Having practically created the modern science of vertebrate paleontology in America, he resented any encroachment upon the particular fields of research in which he was engaged. This attitude frequently developed feelings of hostility in other investigators, and often alienated him from co-workers in his department of science. Nevertheless, he labored faithfully for the truth as revealed in his work, and was ready to change opinions and published statements whenever facts seemed to warrant it.

The subject of the present sketch was born near Lockport, New York, October 29, 1831. His parents were Caleb and Mary Peabody Marsh, formerly of Danvers (now Peabody), Massachusetts. His early education was obtained in the schools of Lockport and at the Wilson Collegiate Institute, Wilson, New York. A residence in a region rich in minerals and fossils is apt to attract the attention of a youth possessing healthy intelligence, and young Marsh soon shared his vacation time between the normal pursuits of shooting and fishing and the more unusual vocation of collecting minerals and fossils. By the time he was nineteen years old he had thus acquired the taste for scientific subjects which was destined to grow and dominate the remainder of his life.

In 1851 he entered Phillips Academy, at Andover, Massachusetts, and continued his studies there until graduation in 1856. He immediately entered the freshman class in Yale College, pursuing the regular classical course, and receiving the degree of B. A. in 1860. Graduate courses in the natural sciences were continued in the Sheffield Scientific School during the two years following (1861–'62). The long summer vacations from 1851 to 1862 were occupied in collecting minerals and fossils from New York, New England, and Nova Scotia. To the latter region he made five trips during this interval, and obtained much valuable experience and scientific material. On his second visit (1855) he found some fossil vertebræ in the Coal Measures at South Joggins, representing a new and important vertebrate animal (*Eosaurus*). This discovery finally directed his studies into the channel which became his life-work. At this time, however, his interests were about equally divided between invertebrate paleontology and mineralogy, and it is worthy of note that his first scientific paper was published in the American Journal of Science in 1861, under the title "The gold of Nova Scotia."

The description of *Eosaurus* did not appear until 1862, seven years after its discovery. Even then it cannot be said that he had developed a strong liking for vertebrate paleontology. This closes the account of his student life in American schools.

The next three years were passed in study abroad, in the universities of Berlin, Heidelberg, and Breslau. He attended lectures and took special courses with H. Rose, G. Rose, Ehrenberg, Peters, Rœmer, Grube, and Gœppert. The vacations were occupied, as before, by geological excursions. He visited the most important localities in Europe, and obtained extensive collections. His official connection with Yale College began by his appointment, in 1866, to the chair of professor of paleontology. This title he held in high esteem, as it was the first established either in this country or elsewhere.

After attending the meeting of the American Association for the Advancement of Science at Chicago, in 1868, Marsh went as far west as Nebraska and Wyoming, along the route of the Union Pacific railroad, then just opened. . This trip gave him a foretaste of the inexhaustible fossil riches of the Rocky Mountain regions, and thenceforth his energies were mainly devoted to their exploration. Scientific expeditions to the western country were undertakings of considerable magnitude in those early days. There was but one railroad in the United States across a region measuring fifteen hundred miles square. White settlements were sparse and remote. Most of the country was unmapped, and with the exception of a few transcontinental trails, almost the whole western half of the continent, save the regions bordering the Pacific, was a boundless expanse of unknown arid plains, mountains, and valleys. Added to these conditions were the indigenous tribes of war-loving Indians, hostile to the whites. Under such circumstances travel was slow, difficult, and dangerous. It was necessary to have an escort of soldiers and guides, experienced in western life and Indian warfare.

The first Yale scientific expedition was organized and engineered by Marsh in 1870. The party consisted of thirteen persons besides the officers and men of the military detachments who escorted them from various military posts along the route. They explored the Pliocene deposits of Nebraska and the Miocene of northern Colorado, then crossing into Wyoming they made collections in the Eocene (Bridger basin), and passing south discovered a new Eocene basin in Utah (Uintah basin). At each of these places many important finds were made. The party next visited California, where minor collections were obtained from the Pliocene. Returning, they spent some time exploring the Cretaceous beds of western Kansas, so rich in the remains of aquatic reptiles, and now famous for having furnished the first toothed birds and American toothless flying reptiles.

The second, third, and fourth Yale scientific expeditions (1871, 1872, 1873) were modeled after the first. New regions in the West were visited, and extensive series of remains of extinct animals were obtained. Coincident with these discoveries, Marsh published frequent scientific papers describing and illustrating the more important forms, and paleontological literature was enriched by the addition of more startling and wonderful types of animal life than had been hitherto known from the rest of the world.

Owing to Indian outbreaks and a general uneasiness in the West, no regular expedition was organized in 1875. Late in the fall, however, Marsh went to the Badlands of Nebraska and Dakota accompanied by an escort from Fort Laramie to the Red Cloud agency. The consent of the Indians was deemed necessary to search for fossil bones in their country.

A treaty was obtained with difficulty, and then assistance was withheld. Nevertheless, with great hardship owing to extreme cold, the party succeeded in reaching the desired region, and made important discoveries, among which numerous remains of the gigantic Brontotheridæ are the most noteworthy.

The rapid settlement and development of the West rendered it no longer necessary to fit out expensive expeditions, especially as many of the localities were easily accessible by railroad. Therefore, after 1876, local collectors and small parties were employed in continuing the work of collecting fossils so successfully begun by the Yale scientific expeditions. Nearly every season, however, Marsh visited the localities where work was being carried on, and some time each year was spent in reconnaissance for new fields of labor.

Professor Marsh's life was remarkably free from the petty annoyances of poor health which so often interfere with human comfort and ambitions. In the midst of his scientific work and while making plans for the growth of the museum, he was suddenly overtaken by the malady which resulted in his death. He died of pneumonia, on March 18th, 1899, in his sixty-eighth year, after an illness of about a week. His work as an investigator in natural science, his wonderful scientific collections, and his munificence to Yale are his legacies to the higher education of mankind.

Although Marsh was an ardent collector in archeology, he published very little on this subject, and his paper (1866) on an ancient sepulchral mound near Newark, Ohio, is practically the only one. His three mineralogical papers, published between 1861 and 1867, show the results of considerable labor and careful investigation. They treat of the gold of Nova Scotia, a zeolite mineral from the same region, and a catalogue of the mineral localities of the maritime provinces of Canada.

In the field of invertebrate paleontology he likewise was an indefatigable accumulator of material, though after 1869 he published nothing in this department. Two papers presented some annelids considered as new, from the Jurassic of Germany. Another showed the origin of the double lobe-lines in *Ceratites.* His papers on American invertebrates comprised a description of a new genus of fossil sponge (*Brachiospongia*), a new form of crustacean trail from the Potsdam sandstone, and a note on color markings in Endoceras. He also showed that Palæotrochis and Lignilites were not of organic origin, though the contrary had been previously supposed.

In the domain of geology his chief interests lay in the formations from which he secured important series of fossil vertebrates. Probably his greatest geological discovery was the Uinta basin, an Eocene deposit of the eastern Uinta mountains. It was first visited in 1870. Having studied most of the Tertiary lake basins in the Rocky Mountain region, he gave, in 1875, a synopsis of their geological features. As a natural result of studying geology in Germany, he was much impressed with the methods of marking the separate horizons by means of some characteristic fossil. He believed the vertebrates were the most sensitive time-markers, and therefore endeavored to determine and limit geological horizons wholly by fossil vertebrate remains. The inherent fault of this system is that the vertebrates are not always the most highly differentiated and specialized types in any given fauna, and it is these qualities alone that can be safely employed in organic chronometry. This method is usually of great value in fresh-water deposits rich in vertebrate remains, but it can be seldom used to advantage in marine sediments or in formations containing a scanty vertebrate fauna. Thus, while the name Equus beds is very appropriate for a horizon in the Pliocene, on account of the abundance of remains of fossil horses, the same cannot be said of the term Eosaurus beds as an equivalent of the entire series of the Coal Measures, especially as but two vertebræ of this animal have ever been discovered. Geological facts will be found scattered through many of his publications dealing principally with fossil vertebrates. One of the latest problems to interest him was the age of the series of variegated clays extending from Marthas Vineyard south along the Atlantic coast into Maryland. His investigations led him to refer them to the Jurassic, a formation which had been considered as absent in eastern North America.

There yet remains for consideration the real work of his life, his publications on the fossil vertebrates, and it is at once evident, from a glance at his bibliography, that his chief researches were upon the reptiles, birds, and mammals. There are three papers on fossil fishes, containing notices of several new forms, but no real research in this class was ever undertaken by him. The amphibians also claimed but little attention, and his observations on the metamorphosis of the recent Siredon into Amblystoma and two brief notices of amphibian footprints in the Devonian and Carboniferous comprise the whole.

It is with extreme hesitation and a sense of inadequacy that the writer ventures to review, even in the briefest and most superficial manner, the work which undoubtedly constitutes the literary essence of his life-work. Future investigators alone can critically estimate the great mass of facts which Marsh brought out and which he wove into the departments of fossil reptiles, birds, and mammals.

His most comprehensive work, and in many ways the most masterly, is the address delivered before the American Association for the Advancement of Science, at Nashville, in 1877. In this paper, entitled the "Introduction and succession of vertebrate life in America," he traced the introduction of the various types of vertebrate life then known in America, beginning with the lowest fishes and ending with man. The amount of knowledge on the lower classes of vertebrates, including the reptiles, was then too meager to enable him to give more than occasional hints as to their phylogeny. But his handling of the Mammalia showed the clearest insight into the development and affinities of many of the important types and marked him as a true philosopher.

A glance at the modern text-books of geology and paleontology reveals how much America has done for the fossil vertebrates in the three classes of reptiles, birds, and mammals. It will also show that Marsh contributed more than any other investigator toward the prominence now accorded to the American forms.

His work on the Reptilia is not equally divided among the various orders, for the Dinosauria claimed his attention above all others. To this group he lent his best efforts, and he compassed it so thoroughly as to be its sole master. It seems only necessary in this place to notice the complete restorations he made of some of these remarkable animals. In this list are included *Anchisaurus*, *Brontosaurus*, *Laosaurus*, *Ceratosaurus*, *Camptosaurus*, *Stegosaurus*, *Triceratops*, and *Claosaurus*. It must be remembered that nearly all these animals were of gigantic stature, some of them the largest land animals yet known, and also that each restoration represents a number of separate investigations on the structure of the skull, the limbs, the vertebræ, the pelvis, etcetera. In most cases only by this means was it possible to bring together gradually, part by part, until the sum of the knowledge warranted a complete representation of the skeleton. The material of many of the genera he described is still in these various stages of progress, awaiting new additions of portions yet unknown in order to form a finished conception of the entire animal. His extensive report on the Dinosaurs of North America, published in 1896, gave a synopsis of what he had accomplished up to that time; but as remarked elsewhere their philosophical treatment he had reserved for his final monographs.

Probably among the Reptilia next in importance to his work on the Dinosauria is that on the Mosasaurs. In this he first announced the discovery of the dermal armor, the position of the quadrate, the finding of the stapes, the columella, the hyoid, the sclerotic plates, the quadrato-parietal arch, the malar arch, the transverse bone, the pterygoids, the pterotic bone, the sternum, the anterior limbs, the posterior limbs, the length of the neck, and details of the pelvic region. Thus he contributed a knowledge of some of the most essential characters of the skeleton in this group. In other groups of aquatic reptiles he also brought out new genera and types of structure. Prominent among these may be mentioned *Baptanodon*, a toothless ichthyosaurian. Marsh was the first to describe the remains of fossil serpents in the western Tertiary deposits, and likewise the first to discover the remains of flying reptiles in America. The latter were of unusually large size and remarkable for the absence of teeth.

The acquisition of a unique specimen of pterodactyl from the lithographic slates of Bavaria enabled him to supply the long sought information regarding the wing and caudal membranes. Notices of a number of new species of fossil crocodiles, lizards, and turtles complete this survey of his work on the Reptilia.

Practically most of the present knowledge of extinct bird life in America is contained in Marsh's publications, which include descriptions of numerous species, ranging from the Jurassic to the Post-Pliocene. Unquestionably the one discovery which is always foremost in men's minds in a consideration of his work is the determination of an extinct order of birds possessed with teeth. The study of the dinosaurs and toothed birds showed that one by one characters considered as avian were likewise present in reptiles, and that many reptilian characters were present in these primitive birds; so that at the end there did not seem much else besides feathers to distinguish them. Marsh's investigation of fossil birds led to the publication, in 1880, of his first monograph, "Odontornithes: a monograph on the extinct toothed birds of North America." In this volume he carefully figured and described all the known types, and presented complete restoration of the two leading genera *Hesperornis* and *Ichthyornis*. He concluded that birds most nearly resemble some of the small dinosaurs from the American Jurassic, and that both classes originated at least as far back as the Trias or late Paleozoic, in some sauropsid type.

A discovery which rivalled that of the toothed birds, although not so wholly his, was the genealogy of the horse. Huxley and Kovalevski traced the equine branch through the Pliocene to the Upper Miocene in Europe, but the true and remote ancestry remained unsolved until the American types were described by Marsh. He showed that a primitive and diminutive polydactyl horse existed in the Lower Eocene, and that from this type, by gradual and progressive change through successive horizons of the Eocene, Miocene, and Pliocene, there had been evolved all the intermediate stages leading to the modern horse.

Next in importance and interest should be noticed the series of papers culminating in the monograph of the Dinocerata issued in 1886 by the United States Geological Survey. His work in other groups of mammals is scattered through a large number of separate papers, and contributions were made to every known order. The Tillodontia comprise one of the most remarkable of the types. Among others are the first remains of fossil Primates, Cheiroptera, and Marsupialia, known from North America. The Brontotheridæ and Coryphodontia received considerable attention. A monograph had been begun on the former, and restorations of a typical genus of each were published.

One general conclusion of much significance was the outcome of his researches on the mammals. It was that the Tertiary genera possessed very small brains. As a single example, Dinoceras may be taken. This animal was but little inferior to the elephant in bulk, but its brain capacity was not more than one-eighth that of existing rhinoceroses.

The first Mesozoic mammal in America was described by Emmons, in 1857, from the Triassic of North Carolina. Marsh, by his extensive discoveries, was enabled to fill up the gaps to the Tertiary with many genera and species from the western Jurassic and Cretaceous. Probably nine-tenths of all the Mesozoic mammals known in the world were described by him, and while these remains are of great interest, yet from their fragmentary condition they are not of the highest scientific value, because little is known beyond the jaws and a few limb bones.

In closing the outline of the discoveries made by this investigator, one cannot help being impressed with their signal brilliancy, their great number, and especially by their unique importance in the field of organic evolution. Were all other evidence lost or wanting, the law of evolution would still have a firm foundation in incontrovertible fact. The study of variation and embryology in recent animals gives hints as to the truth, but Paleontology alone can give the facts of descent.

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In the absence of the author of the following memoir it was read by Mr W. H. Dall.

MEMOIR OF OLIVER MARCY

BY ALJA R. CROOK

By the death of Oliver Marcy on the nineteenth of last March the Geological Society of America lost a Fellow who though but slightly known in the Society may be numbered among its most worthy members.

The scarcity of his scientific publications and the fact that he was at the time of his death a man full of years, being seventy-nine, and in recent years had rarely attended the meetings, explain his limited acquaintance among the younger and more numerous members of the Society. The duties devolving on him from the time of his acceptance of a position as teacher at Wilbraham, Massachusetts, to the day when he closed his office door in University Hall for the last time were such as to leave small opportunity for investigation; and the results of the investigations which he did make were rarely published, because of his conviction that science is burdened by too much rushing into print—too many one-hundred-page reports of a one-page fact—a too common custom of presenting a scientific truth in the same manner as that in which Van Clattercop built a church. His tastes and ambitions led him to study rather than to publication, and students, colleagues, and friends who came in contact with him profited by his studious habits and honored him for his attainments.

His scholarly proclivities were inherited, both sides of the ancestral line being marked by men of literary taste and culture. Among the Marcys have been men prominent in politics—a high-sheriff, a captain, a general, a governor, a United States Senator, a member of the Supreme Court of the United States, a Secretary of State—men successful in business and in the professions—merchants, doctors, lawyers, ministers, college professors and presidents, and explorers.

Oliver Marcy was born at Coleraine, Massachusetts, February 13, 1820, and died at Evanston, Illinois, March 19, 1899. He was the seventh of nine children born to Thomas Marcy. His father died when the lad was eight years old. His mother was so capable, energetic, and devoted that she managed to rear her large family in such a manner that it became an honor to her and a blessing to the community. Of the sons, three received a college education; and later, two of them became ministers and one a college professor; and of the three, two were at one time college presidents.

After obtaining a common school education in his native town, Oliver was able by working during vacations and by spending some intervening years in teaching to graduate at Wesleyan University at the age of twenty-six years. The following year he married Elizabeth E. Smith, of Chatham, a woman of rare qualities of mind and heart—a true companion through their long married life—a lady who has found time and strength to carry on a great work among the poor of Chicago and to whom the Chicago Bohemian Mission will long be a monument.

During his student days young Marcy chose teaching as a profession, and the first position that came to him after graduation was an instructorship in mathematics at Wilbraham Academy. After a year or two, in addition to his other work, a class in geology was assigned to him, although he had had little previous training in that subject—a custom unfortunately common in secondary schools and some socalled colleges even today, on the assumption that although a good training is necessary for teachers of philology or mathematics, any one can teach natural science. When Doctor Marcy came in touch with geology he was attracted by it, and later found in it his chief interest.

After teaching at Wilbraham for sixteen years he was elected to a professorship of natural science in Northwestern University. Conditions were at that time in Evanston, as they were a hundred years ago in Europe, and as they still are in small colleges in the United States, in such a shape that one man had to deal with a multitude of subjects. During the thirty-seven years in which Professor Marcy was connected with Northwestern he taught natural theology, moral science, philosophy, logic, mathematics, chemistry, physics, botany, zoölogy, mineralogy, and geology. His own growth and development were contemporaneous with that of the university. At the time of his election there were eight instructors and thirty-one students. At the time when he delivered his last lecture, there were in the university two hundred and thirty members of the faculty, instructing twenty-two hundred students, besides the forty instructors and seven hundred students in the academy and school of oratory that are conducted under the auspices of the university. Today sixteen men are employed to present the subjects that Doctor Marcy represented.

Twice he was acting president of the university, serving the first time for five years and the second time for part of a year. On the first occasion he was at the height of his activity and influence and had an unusual hold on the student body.

His geological work was begun and continued under unfavorable conditions. His college had done little for him in the subject. Books were few and costly. The many attractive and finely illustrated text books on geology that are accessible to every student now were wanting. Many of the works from which we draw inspiration and which we regard as classics today had not been written. Mantell had not yet written his "Medals of Creation;" Hugh Miller's "Testimony of the Rocks" did not appear till 1856, and "Old Red Sandstone" not until two years later. Dana did not begin to bring out his geologies and mineralogies till Marcy had been teaching a dozen years. Lyell's "Principles of Geology" had passed through several editions, but seems not to have come within Marcy's reach, so that his early knowledge of the science was derived almost wholly from Hitchcock's "Elementary Geology" and from Buckland's "Mineralogy and Geology," and both of these writers were at that time catastrophists.

Materials for illustrating geological facts were even more difficult of access than literature on the subject. As Wilbraham had no museum, Marcy was accustomed to go 20 miles to Amherst to study the collections; yet in spite of these difficulties he became a fine scholar in geological lines.

At the time of his election Northwestern had no museum. An important part of his life-work consisted in building up a museum. During the course of his labors he classified and labeled more than seventy-two thousand zoological, botanical, archeological, and geological specimens.

Burdened thus with the duties of a curator, of a teacher of many subjects, and of a president, he found little time for research and publication in his chosen work; so his publications fail to represent his activity and his attainments. He wrote numerous articles for weekly papers. About sixty of these have come under my notice, and shed much light on his line of thought, the nature of the problems he had to meet, and the traits of his character. Many of the articles are metaphysical in nature, showing that speculative philosophy had strong attractions for him. Many of them discuss the place of natural science subjects in the college curriculum, advocating for them a more important position. Some of them deal with travel and geology. In some of them he opposes "mechanical evolution," advocates catastrophism with his teacher Buckland, and believes in the iceberg theory for drift deposits and glacial scratchings, as Lyell at one time did. But those who would judge Doctor Marcy by these expressions would misrepresent him, for they are but phases in the history of his geological science and not his ultimate position, and his students and those intimate with him know that he did not believe in cataclysm, that he taught the commonly accepted ideas of glaciation, and that he was a thorough evolutionist. This revision of theory and belief was made at an age when most people cling to their conclusions whether the facts warrant them or not, and was possible to him because of his singular freedom from bigotry, his eminent reasonableness, fine scientific spirit, and truly scholarly habits. These qualities, together with his diligence as a student and the strength of his memory, enabled him to become not only a well informed geologist, but in truth a profound scholar in the science.

The only geological monograph * which he published was one on the fossils of the Chicago Niagara limestone, prepared in conjunction with Alexander Winchell, and presented at the Boston Society of Natural History in 1865. This publication was a satisfactory paper in every way.

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* Enumeration of fossils collected in the Chicago limestone at Chicago, Illinois, with description of several new species. Alexander Winchell and Oliver Marcy. Memoirs Boston Soc. Nat. Hist., vol. 1, 1865.

Doctor Marcy's influence was most widely felt as a teacher. At one period of his connection with the university nearly every student in the institution took work with him, and in after life they remembered him with warm regard, so that at the time of his death he had a stronger hold on the alumni than any other man on the faculty.

As a lecturer he was interesting in manner and knew how to arouse enthusiasm. His voice was strong and clear and his style deliberate and positive. He was approachable to students, always meeting them in a frank, cordial manner that impressed them with his kindliness of spirit. He was not critical in small things, but had a broad charity that drew men to him. It is sometimes said that he had little sense of humor. If that be the fact, he often used the little that he did possess. In geology each student was required to make a collection of twenty typical rocks and present them for examination at the close of the course. One young man inherited his from a predecessor in the course and presented it to the Doctor for examination. Professor Marcy said, "Yes, Mr S., I always give that collection a grade of seventy per cent." A classical scholar himself, he appreciated the humor of some of the claims of teachers of the classics. When a term of Greek or Latin origin was employed in geology he would say "Who can tell the meaning of that term?" And no one answering, "Where are some of those students of the classics? Now is their opportunity!"

There was little self-seeking in his nature, and losing himself in his work and in the interests of others he found his own highest good; for few men have been more fortunate in receiving all through life the respect and love due them. Many honors came to him. He was a member of Phi Beta Kappa, the American Association for the Advancement of Science, a Fellow of the Geological Society of America, received the degree of LL. D. from Chicago University in 1873, was dean of the College of Liberal Arts of Northwestern University for twenty years, and twice held the position of president. A fossil oak (*Quercus marcyana*) and a hill in Massachusetts are named in his honor. Expressions of appreciation were not withheld until after his death. He was constantly receiving them, and on his seventy-eighth birthday the alumni presented his protrait to the university. The occasion was an impressive one. The beautiful library-room, adorned with the university royal purple and with flowers and brilliant with electric lights, had been arranged with tables, around which were gathered about two hundred guests. The white-haired, fine-looking gentleman whose birthday was being celebrated sat beside the president of the university, and after several speeches, which expressed the respect and love of the students, alumni, friends, and acquaintances, and the unveiling of the portrait, received an ovation such as rarely comes to a professor.

His death called forth expressions which showed the breadth of his influence. He lies buried under the hemlocks in a wild and picturesque ravine on "Mount Marcy," at Wilbraham, Massachusetts.

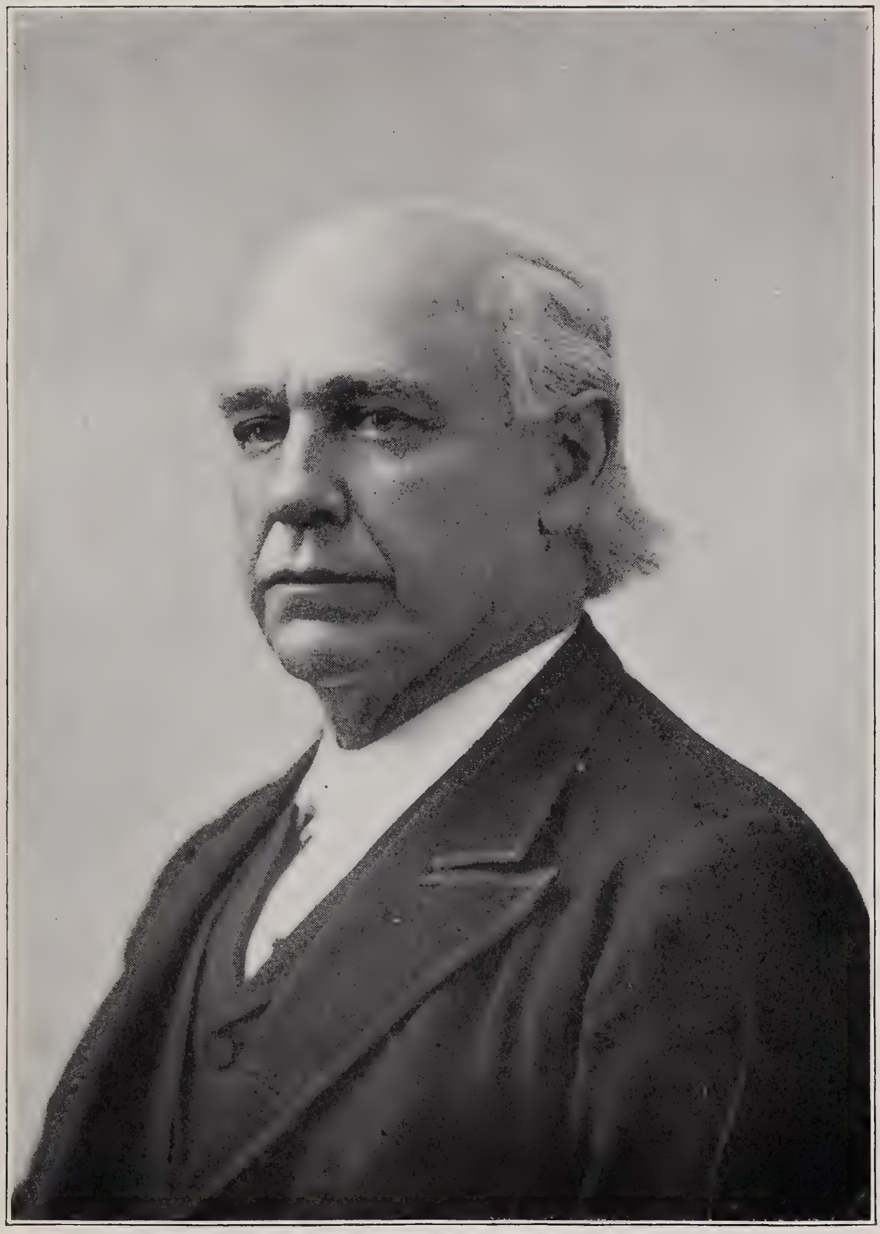
Remarks were made by W. H. Dall, W. H. Niles, W. North Rice, and by the President in testimony of the high character and attainments of Doctor Marcy and of his services to science. especially as a teacher.

MEMOIR OF EDWARD ORTON

BY G. K. GILBERT

Edward Orton, ninth president of our Society, was born at Deposit, Delaware county, New York, March 9, 1829. His father, Samuel G. Orton, a minister of the Presbyterian church, was of New England stock, belonging to a family which lived for several generations in Connecticut. His mother's maiden name was Clara Gregory. He was twice married: in 1855 to Mary M. Jennings, of Franklin, New York; in 1875 to Anna D. Torrey, of Millbury, Massachusetts. He died at his home in Columbus, Ohio, October 16, 1899, having rounded out the allotted span of three score years and ten. Charles, Clara, Edward. and Mary, children of his first marriage, his wife, and her two children, Louise and Samuel, survive him. His son Edward succeeds him as State Geologist of Ohio.

As a boy he lived with his parents in a rural community at Ripley, Chautauqua county, New York, becoming intimately acquainted with farm life and work. He was fitted for college mainly by his father, but spent one year in Westfield Academy, and another in Fredonia Academy. He entered Hamilton College as a sophomore, and was graduated at the age of nineteen. After teaching for a year in the academy at Erie, Pennsylvania, he entered the Lane Theological Seminary (1849), but he was prevented from completing the course by the temporary disability of his eyes. After a year or more of rest and out-of-door life, he resumed teaching in the Delaware Institute at Franklin, New York, where he was assigned the department of the natural sciences. In 1852 he returned to student life, spending six months in the Lawrence Scientific School, and afterward resuming theological studies at Andover Seminary. He was then ordained to the Presbyterian ministry and became for one year the pastor of a church in Downsville, New York. In 1836 he was called to the chair of natural science in the New York State Normal School at Albany, and from 1859 to 1865 was principal of the Chester Academy in Orange county. He was then called to Antioch College



Very truly yours.

Edward Orton.

at Yellow Springs, Ohio, becoming at first principal of the preparatory department, then professor of natural history, and finally, in 1872, president of the institution. The following year he resigned to accept the chair of geology in the Ohio Agricultural and Mechanical College, then in process of organization under the provisions of the act of Congress of 1862. Before the institution was opened he was tendered and had accepted the presidency, and he filled both positions for eight years. This was the formative period of the institution and he had much to do with the shaping of its policy. It grew rapidly and, with enlarging scope, became the present Ohio State University. But while his administrative work gave satisfaction to his associates, it was less to his taste than either teaching or scientific research, and he gladly relinquished it as soon as he could do so without seeming to betray a trust. He resigned the presidency in 1881, but retained the chair of geology during the remainder of his life. His work as an investigator in geology was carried on during his residence in Ohio, and could command only such share of his time as was not consumed by executive and professorial duties.

For thirty years he served the state of Ohio, first as assistant geologist, and later as state geologist. He was vice-president of the American Association in 1885, president of the Geological Society in 1897, and president of the American Association at the time of his death.

This brief outline of Orton's life, dry and statistical though it is, reveals the important fact that his dominant activity, beginning in the field of religious instruction, was successively transferred to secular education and geologic research, so that there are three points of view from which his career might appropriately be considered. Our interest as geologists naturally centers in his labors and influence as a man of science, but it is well to recognize that these were affected in important ways by his earlier and associated activities.

In a sketch of his life which, though anonymous, is clearly autobiographic, Orton says of himself: "Finding that his theological creed was giving way under his later studies [at the Lawrence school], he sought to avert the change by more thorough investigation in this department, and entered Andover Seminary to attend for a year Professor Park's lectures on theology. The experiment was successful to the extent of arresting the change in his views, but after a few years the process was resumed and ended in the replacement of the Calvinistic creed, in which he had been brought up, by the shorter statements of Unitarianism." *

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* Historical Collections of Ohio; Centennial edition, 1889, vol. 2, p. 59. In the compilation of my account of Orton's early life I have drawn freely on this biography.—G. K. G.

This change of belief cost him not only loss of status as a Presbyterian minister, but the alienation of friends, and there followed a period of such unhappy remembrance that he afterward shrank from the mention of it, even to the members of his family. It is to the credit of advancing civilization that here at the end of the nineteenth century our community finds difficulty in realizing how hard was the temporal way of the apostate even at the century's middle.

On leaving the Presbyterian ministry Orton accepted secular teaching as an occupation, but adhered to religious teaching as a duty. Living in communities where there were few Unitarians, he was not connected with a church organization, but he often addressed audiences on religious and ethical topics, and during his connection with the State University he frequently gave a Sunday lecture for the benefit of such students as were not connected with the Columbus churches. This practice and the spirit which actuated it doubtless helped to keep him in touch with the community and contributed to the high esteem and confidence with which he was regarded. It is proper to add that, while his belief in the fundamental doctrines of Christianity survived the perils sometimes attributed to scientific training, his science suffered nothing from theologic bias. His writings ascribe the phenomena of nature to natural causes, and his hypotheses seek verification by appeal to visible and tangible facts.

Of his work as an educator it is not necessary that I attempt to speak, because it has already been treated by the abler pen of Doctor Mendenhall,* who was for years his associate. It contributed to his success as a geologist chiefly by making him master of the art of presentation alike from the platform or through the printed page.

Orton's interest in geology was not developed until early manhood. His first work appears to have consisted of observation and collection carried on as an aid to teaching, and it was not until his forty-first year that he made contribution to the literature of the science. In the year 1869 the Second Geological Survey of Ohio was organized, with John S. Newberry as State Geologist and Edward Orton and E. B. Andrews as Assistant Geologists. Orton was at that time professor of natural sciences in Antioch College and did not relinquish his college work. The southwest quarter of the state, called the third district, was assigned him as his field of survey, and an assistant was given him. After a few seasons of active field-work, in which the areal geology was completed

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*Edward Orton, educator. By T. C. Mendenhall. Address read at Columbus, Ohio, November 26, and printed by the Ohio State University in a memorial volume. Printed also in *Science*, vol. 11, 1900, pp. 6–11. A biographic memoir by I. C. White is published in the American Geologist (vol. xxv, 1900, pp. 197–210), and one by J. J. Stevenson in the Journal of Geology (vol. viii, 1900, pp. 205–213).

and reported on by counties, the attention of the principal assistants was given to various special topics. Newberry, who had been divided in residence between Ohio and New York, removed altogether from Ohio, and about the same time Orton's field of college work was removed from Yellow Springs to Columbus. Votes of state money, except for publication, had practically ceased, and it remained only to prepare and print the topical volumes of the series of projected reports. The editorial work gradually devolved on Orton. He also continued to devote much time to field-work, and he came to constitute the survey in fact some years before Newberry relinquished nominal control. Meanwhile the development of various mineral resources, especially the fuels, coal, gas, and oil, created a popular demand for more geologic work, and a third geological survey was finally established under Orton's directorship. In 1882 he was charged by the legislature with the completion of delayed reports of the second survey, and a year later was appointed State Geologist by Governor Foster. The new organization, restricting attention to the geology and industries of useful materials, assumed the character of a continuous economic survey and has been maintained to the present time.

Orton's personal contributions to the geology of Ohio began with the details of areal, stratigraphic, and structural geology in the third district. These were described and published in thirteen county reports and two reports on the classification and distribution of strata. His data on various economic materials, accumulated during the areal survey, were supplemented by visits to other parts of the state and were generalized in a series of special papers. Iron ores, building stones, lime, gypsum, clays, rock waters, and coal were thus treated, the discussion of coal being elaborated by horizons and districts. From about the year 1884 attention was largely concentrated on natural gas and oil, and as to these Orton soon became a recognized expert. In addition to his voluminous writings on this subject for the Ohio reports, he made a number of contributions to scientific and technical journals, and his researches were carried to other states. Chiefly for the purpose of verifying a general theory of the relations of gas, oil, and brine in subterranean reservoirs, he extended the investigation of the natural gas fields in northwestern Ohio so as to include the cognate fields in eastern central Indiana; and he was called by the officers of geological surveys in Kentucky and New York to examine and report on gas and oil fields.

The earlier part of his geologic work consisted of observation and primary generalization, the determination and record of local phenomena and their arrangement under categories already established. His later work was largely economic, the application of geologic principles and local geologic knowledge to industrial questions. His contributions to theory came late, were few in number, and were broadly founded on the facts of his own observation. He never entered the field of speculation. He epitomized in a single career the fundamental method of science—first, observation, then theory, then verification through renewed observation, and finally the application of theory to particular cases for the promotion of human welfare—and by thus exhibiting pure and applied science in close and logical association he gave to his community an object lesson of great value.

Beginning life as a preacher and never ceasing to be a religious instructor, continuing life as a teacher and remaining a teacher to the end, and bearing in middle life an important administrative trust, he reserved scant time for research; yet despite these limitations he became, in fact as well as by official designation, the first geologist of his state, and he attained the foremost rank in an important department of theoretic and applied geology. Quiet in manner and retiring in disposition, challenging attention by no brilliant and striking theories, refraining from the discussions of the more general problems of his science, and adhering modestly to those of his state and his specialty, he was yet so appreciated by his fellows that he received the highest honor in the gift of American geologists and the presidency of the greatest body of American scientists.

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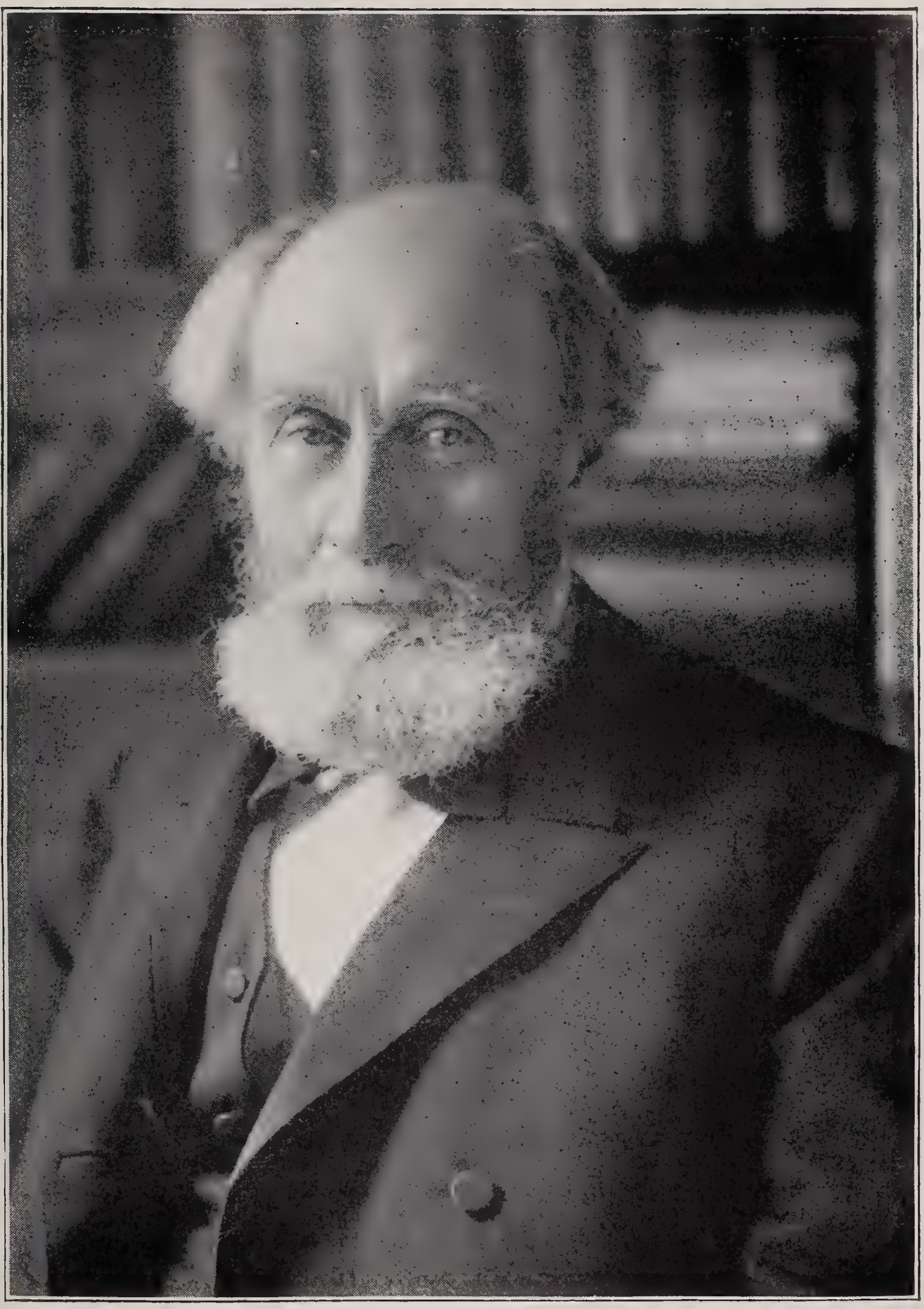
MEMOIR OF SIR J. WILLIAM DAWSON

BY FRANK D. ADAMS

It is with deep regret that we record the death of Sir William Dawson, which took place at Montreal on the morning of November 19, in the eightieth year of his age. In him Canada loses a distinguished geologist and naturalist, as well as one who was intimately identified with educational work of all kinds, but more especially with higher education in the province of Quebec.

Sir John William Dawson, having been born at Pictou on October 13, 1820, was a native of Nova Scotia, a province which has produced more than its share of the Canadians who have risen to eminence in the various walks of life. His father, James Dawson, was from near Aberdeen, Scotland, and came to Nova Scotia to fill a position in a leading business house in Pictou, and on the termination of his engagement began business on his own account, becoming in the course of time one of the chief ship-builders in that part of Nova Scotia. James Dawson had but two children, of whom Sir William was the elder. The younger died at an early age, leaving Sir William thus the sole survivor of the family.



Truly yours

J Wm Dawson

While still at school in Pictou, at the age of twelve he developed a love for natural science, inherited from his father, and made large collections of fossil plants from the Nova Scotia Coal Measures, so well exposed about his native place. He speaks of himself at that time as being a "moderately diligent, but not a specially brilliant pupil." On leaving school he studied at Pictou College and subsequently at the University of Edinburgh. While at the former seat of learning, at the age of sixteen, he read before the local natural history society his first paper, having the somewhat ambitious title "On the structure and history of the earth."

At Edinburgh he studied under Jamieson, Forbes, and Balfour, as well as with Alexander Rose, whom he refers to in some notes and reminiscences as a single-hearted mineralogist and the greatest authority on the mineralogy of Scotland. He records his impression of the University of Edinburgh at that time as being "a very imperfect school of natural science in comparison with our modern institutions," and adds: "Jamieson, who was my principal teacher, devoted a large portion of the earlier lectures of his course to physiography, and the rest to minerals and rocks, but I was surprised to find how little even some of the most eminent English geologists of the day knew of mineralogy, and how uncertain in consequence was their diagnosis in the field of the nature of rock masses."

In 1841 he met, however, two men with whom he was afterward intimately associated in his work—Sir Charles Lyell, who more than any other man gave form to modern geological science, and Sir William Logan, who gave the first great impetus to the study of the older rocks of the northern half of the North American continent and who founded the Geological Survey of Canada.

He returned to Nova Scotia in 1847, and two years later went to Halifax to give a course of lectures on natural history subjects in connection with Dalhousie College, and organized classes for practical work in mineralogy and paleontology. These were attended by students, citizens, and pupils of higher schools—a foreshadowing of university extension. In 1850, at the age of 30, having already attracted some attention by the publication of a number of papers, reports, and lectures, he was appointed Superintendent of Education for Nova Scotia. His work in connection with this position obliged him to travel continually through all parts of the province, and on these journeys he accumulated that immense mass of information concerning the geology and mineral resources of Nova Scotia which is incorporated in his largest work—that entitled "Acadian Geology."

Sir Charles Lyell, in 1841, on his first visit to America, met Sir William and was by him conducted to many places of geological interest in Nova Scotia, and on his subsequent visit in 1852 they together continued their studies in Nova Scotian geology. In a letter to Leonard Horner, dated September 12 of this year, Lyell writes:

> "My companion, J. W. Dawson, is continually referring to the curious botanical points respecting calamites, endogenites, and other coal plants, on which light is thrown by certain specimens collected by him at Pictou. He told me that the root of the pond lily *Nymphæa odorata*, most resembled Stigmaria in the regularity of its growth, and Doctor Robb showed me a dried specimen, a rhizoma, which being of a totally different family and therefore not strictly like, still suggests the probability of the Stigmaria having grown in slush in like manner."

And in another part of the same letter he, referring to the now celebrated Joggins section on the coast of Nova Scotia, says:

> "Dawson and I set to work and measured foot by foot many hundred yards of the cliffs, where forests of erect trees and calamites most abound. It was hard work, as the wind one day was stormy, and we had to look sharp lest the rocking of living trees just ready to fall from the top of the undermined cliff should cause some of the old fossil ones to come down upon us by the run. But I never enjoyed the reading of a marvelous chapter of the big volume more. We missed a botanical aide-de-camp much when we came to the top and bottoms of calamites and all sorts of strange pranks which some of the compressed trees played."

In 1854 Forbes, who was professor of geology and zoology in the University of Edinburgh, died, and Lyell wrote to Sir William, advising him to apply for the chair, promising him his support and that of a number of his influential friends, while Sir William's "Acadian Geology," which had just been published in Edinburgh, testified to his abundant fitness for the position. He was about to set sail for Scotland to prosecute his candidature for the chair when he received word that the place had been filled, sooner than had been anticipated, by the appointment of a zoologist who had been strongly supported by the medical school of the university, but, by a strange coincidence, he received, almost on the very day that he was to sail for Scotland, a letter offering him the principalship of McGill University.

This institution, founded by royal charter in 1821, had made but slow progress in its earlier years, and was at this time, through litigation and other causes, almost in a state of collapse. Sir William, then Mr Dawson, was pointed out to the governors of the college by Sir Edmund Head, then Governor-General of Canada, as a man who, if his services could be secured, was eminently fitted to undertake the task of reconstructing it.

The services of Mr Dawson were accordingly secured, and in 1855 he assumed the principalship of McGill University, stipulating at the same time that the chair of natural history should be assigned to him.

The university as he found it had three faculties and but sixteen professors, a number of whom gave only a portion of their time to university work, while the buildings and equipment were wretched. When it is stated that the university has now one hundred and twenty professors and instructors of various grades and an equipment which is in all departments fairly good and in some of them unsurpassed, some idea may be gained of the progress which the institution made under Sir William Dawson's care and guidance.

As professor of natural science Sir William at this time delivered courses in chemistry, botany, zoology, and geology, and natural science became a very favorite study among the students, for he was an excellent lecturer, and his enthusiasm for these subjects was communicated to all who heard him. As years went on the instruction in the first three of these subjects was undertaken by others, and a special chair of geology and paleontology was endowed by his old friend and co-worker, Sir William Logan, a chair which he held until his final retirement. His teaching work, however, formed but a small part of his daily labors. In addition to administering the affairs of the university, he was first and foremost in every movement to further education in the province, and no educational board was complete without him. He was the honorary president of the Natural History Society and never missed a meeting or a field day, and also identified himself closely with many other societies in Montreal, and spared neither time nor labor in their behalf.

Over and above all this he found time to carry out original work along several lines, achieving most valuable results, as well as to write many popular works on science, more especially in its relation to religion. Original investigation he always considered to be one of the chief duties and pleasures of a man of science. Most of his work along these lines was done during his summer vacations; in fact, he was led to accept the position of principal in McGill chiefly by the fact that the vacations gave him leisure and opportunity for work of this kind.

He was always very progressive in his ideas relative to the scope and development of university teaching, and was continually urging the endowment of new chairs and the broadening of university work, so that all young men wishing to train themselves for the higher walks of life might in the university find their needs supplied. As an instance of this it may be mentioned that so far back as 1858 he succeeded in establishing a school of civil engineering, which, after a severe struggle of five years, succumbed to some unfriendly legislation, only, however to be revived by him in 1871, and developed into the present faculty of applied science of McGill University, with its numerous departments, its full staff of instructors, and excellent equipment. Sir William, furthermore, never hesitated, if funds were not forthcoming in sufficient amount for these purposes, to subscribe large sums out of his own limited private means, and he was also the continual helper of needy students desiring to avail themselves of the university's teaching.

Sir William received the degree of M. A. from the University of Edinburgh in 1856 and the degree of LL. D. from the same university in 1884. His attainments and the value of his contributions to science were widely recognized, and he was elected an honorary or corresponding member of many learned societies on both sides of the Atlantic. He was made a Fellow of the Geological Society of London in 1854 and of the Royal Society in 1862. He was the first president of the Royal Society of Canada, and has occupied the same position in the Geological Society of America and in both the American and British Associations for the Advancement of Science.

In 1883 he attended the meeting of the British Association for the Advancement of Science, at Southport, in the interest of the meeting in Montreal in the following year, and spent the ensuing winter in Egypt and Syria studying the geology of those countries, more especially in its relation to sacred history, and accumulated much information on this subject, which appeared later in his book entitled "Modern Science in Bible Lands," as well as in other books and papers which he published subsequently.

He took an active part in the organization and proceedings of the meeting of the British Association for the Advancement of Science in Montreal in 1884, on the occasion of which he received the honor of knighthood.

In 1893 Sir William was seized with a very severe attack of pneumonia, and his health became so seriously impaired that he was obliged to give up his work for a time and spend the winter in the southern United States. His strength, however, was not restored, and he resigned his position as principal of McGill University in June, 1893, and retired from active work. During the later years of his life his strength gradually ebbed away, and what little work he could undertake consisted in arranging his collections and working on some unfinished papers. Several of these were published in 1894 and 1895; but the years of quiet labor in his favorite pursuits to which he looked forward at this time were cut short by a series of sharp attacks, culminating in partial paralysis, which forbade further effort. He passed away on the 19th of November peacefully and without pain.

Lady Dawson, with three sons and two daughters, survive him. His eldest son, Doctor George M. Dawson, the present director of the Geological Survey of Canada, has inherited his father's taste for geological studies and has achieved wide distinction in the world of science.

Sir William's first original contribution to science was a paper read before the Wernerian Society of Edinburgh in 1841 on a species of field mouse found in Nova Scotia. From that time onward he was a continuous contributor to scientific journals and to the publications of various learned societies. His papers were very numerous and covered a wide range of subjects in the domain of natural history. The most important work of his earlier years was an extended study of the geology of the eastern maritime provinces of the Dominion of Canada. His results are embodied in his "Acadian Geology," already mentioned. It is a volume of nearly 1000 pages, is accompanied by a colored geological map of Nova Scotia, and has passed through four editions. In writing to Sir William in 1868 Sir Charles Lyell says of this work:

> "I have been reading it steadily and with increased pleasure and profit. It is so full of original observations and sound theoretical views that it must, I think, make its way, and will certainly be highly prized by the more advanced scientific readers."

It is the most complete account which he have of the geology of Nova Scotia, New Brunswick, and Prince Edward island, although since it appeared large portions of these provinces have been mapped in detail by the Geological Survey of Canada and Sir William's conclusions modified in some particulars. In carrying out this work Sir William paid especial attention to the paleontology of the Carboniferous system and to the whole question of the nature and mode of accumulation of coal. He subsequently studied the paleontology of the Devonian and Upper Silurian systems of Canada, discovering many new and important forms of plant life.

In 1884 he began the study of the Cretaceous and Tertiary fossil plants of western Canada, and published the first of a series of papers on the successive floras from the Lower Cretaceous onward, which appeared in the Transactions of the Royal Society of Canada. He also contributed a volume, entitled "The Geological History of Plants," to Appleton's International Scientific Series. In 1863 he published his "Air breathers of the Coal period," in which were collected the results of many years' study in the fossil batrachians and the land animals of the Coal Measures of Nova Scotia. The earliest known remains of Microsauria were then discovered by him in the interior of decayed tree stumps in the Coal Measures of South Joggins. The results of his later studies in these creatures were embodied in a series of subsequent papers which appeared from time to time.

On taking up his residence in Montreal his attention was attracted to the remarkable development of Pleistocene deposits exposed in the vicinity of the city, and he undertook a detailed study of them, and especially of the remarkably rich fossil fauna which they contain. He also studied subsequently the Pleistocene deposits of the lower Saint Lawrence river and instituted comparisons between them and the present fauna of the gulf of Saint Lawrence and of the Labrador coast.

He was led by these studies to believe that the deposits in question had been accumulated largely through the action of sea-borne ice, and being anxious to study the evidence on which the continental geologists had based their views of the high efficiency of land ice as an eroding agent, he visited Switzerland in 1865 and there studied the phenomena of glacial action. By these studies he was led to attribute much less importance to land ice as an eroding agent than was commonly assigned to it. "I was also led to believe," he wrote shortly before his death, "that while the carrying power of a glacier is undoubtedly great, it is altogether inferior to that of sea-borne ice, whether in the form of ice-fields, grinding on the shores, or of icebergs, and these views, arrived at and published in 1865, I have ever since consistently maintained."

The results of his studies on the Canadian Pleistocene appeared in a series of papers as the work progressed, and were finally embodied in a volume entitled "The Canadian Ice Age," which was issued in 1893 as one of the publications of the Peter Redpath Museum of McGill University. This is one of the most important contributions to the paleontology of the Pleistocene which has hitherto appeared.

As Sir William was always much more interested in the history of life than in any of the inorganic aspects of the science of geology, he considered one of his most important contributions to scientific knowledge to be the discovery of *Eozoon canadense.* The true character of this remarkable object, concerning which there has been so much discussion, can hardly be considered even yet as definitely settled. Its resemblance microscopically to certain organic forms is so remarkable that some of the most experienced observers have accepted it as of organic origin. Its field relations, however, leave but little doubt that it is inorganic.

The literature of this subject, which includes many papers by Sir William, is quite voluminous, but the chief facts are summed up in his book entitled "The Dawn of Life," which appeared in 1875.

Sir William was also a prolific writer of popular works on various geological topics. Among these may be mentioned his "Story of the earth and man," his "Fossil men and their modern representatives," his "Meeting place of geology and history," and his "Modern science in Bible lands." These books, all written in a very entertaining style, had a wide circle of readers, and many of them passed through several editions.

Other volumes from his pen, as well as many papers contributed to various religious publications, treated of the relation of science and religion. One of the earliest of these was entitled "Archaia," and dealt with the relations of historical geology to the Mosaic account of the creation. In others he considered the relation of the evolutionary hypothesis to religious thought.

Sir William was a Presbyterian of the old school and strongly opposed to all theories of the evolution of man from brute ancestors, nor would he allow anything more than a very moderate antiquity for the species. The study of geology, too, he would have emancipated from "that materialistic infidelity which by robbing nature of the spiritual element and of its presiding divinity makes science dry, barren, and repulsive and diminishes its educational value."

These works on the relation of science and religion, while they undoubtedly met a popular need, have but a transitory value, and they are not the works by which Sir William Dawson will be remembered. His reputation is founded on the great contributions to our permanent stock of knowledge which he has made and which are embodied in his works on pure science, representing achievements of which any man might well be proud. His name has been perpetuated in connection with the geological department of his university by the establishment of a second chair in geology, to be known as the Dawson chair, which has just been endowed in his memory by Sir William Macdonald.

Sir William was a man of quiet geniality, gentle and even deferential in manner, but decided in opinion and firm in action. The pre-eminent note of his character was sincerity and singleness of purpose. His loss will be felt by all who knew him, but especially by the members of the university with which he was so long connected.

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The Primeval flora (a lecture given in New York): *Nat. Sci. News*, March 21, 1896, vol. 2, no. 8, pp. 29–32.

Pre-Cambrian fossils, especially in Canada. (Read in Geological Section, British Association, Liverpool meeting, September, 1896.) *Can. Rec. Sci.*, July, 1896, pp. 157–162, Montreal.

1897.

On the genus Lepidophloios, as illustrated by specimens from the Coal Formation of Nova Scotia and New Brunswick: *Trans. Roy. Soc. Can.*, second series, vol. 3, 1897, sec. 4, pp. 57–78, pls. 1–14. (Issued as separate.)

Note on Carboniferous Entomostraca from Nova Scotia, in the Peter Redpath Museum, determined and described by Professor T. Rupert Jones and Mr Kirby. (Reprinted from the *Can. Rec. Sci.*, January, 1897.) Montreal, pp. 316–323. (McGill University, Montreal, paper from the department of geology, no. 7.)

Note on Cryptozoon and other ancient fossils: *Can. Rec. Sci.*, vol. 7, pp. 203–219, 1 pl., Montreal, April, 1897.

Relics of primeval life, 336 pp., London, New York, etc. (Being lectures on pre-Cambrian fossils. Lowell Institute, Boston, 1895.)

1898.

Addendum to note on Nova Scotia Carboniferous Entomostraca: *Can. Rec. Sci.*, July, 1897, vol. 7, p. 396 (issued July, 1898), Montreal.

Communication on Mr Mello's paper on primitive man: *Trans. Victoria Institute*, vol. 30, 1898, pp. 253-255, London.

Communication on Mr Mello's paper on neolithic man: *Ibid.*, pp. 298, 299.

1899.

Note on an Echinoderm collected by Doctor Ami at Besserers, Ottawa river, in the Pleistocene (Leda clay): *Ottawa Naturalist*, December, 1899, vol. 13, pp. 201, 202, Ottawa.

The presentation of scientific communications was declared in order, and the first paper presented was

PHYSIOGRAPHIC TERMINOLOGY WITH SPECIAL REFERENCE TO LAND FORMS

BY W. M. DAVIS

Remarks were made by the President.

The second paper, read by the senior author, was entitled:

CAMASLAND, A VALLEY REMNANT

BY GEORGE OTIS SMITH AND GEORGE CARROLL CURTIS

Remarks were made by W. M. Davis, W. G. Tight, and the senior author. The paper is printed in full in this volume as pages 217 to 222.

The third paper was

SOME COAST MIGRATIONS, SOUTHERN CALIFORNIA

BY BAILEY WILLIS

The paper is printed as pages 417 to 432 of this volume.

The last paper of the morning session was then read:

SUBMERGED FOREST OF THE COLUMBIA RIVER

BY G. K. GILBERT

The paper was discussed by S. F. Emmons, J. A. Holmes, and G. B. Shattuck.

The Society adjourned for luncheon, and reassembled in the afternoon. The first paper of the afternoon session was the following:

PHYSIOGRAPHIC DEVELOPMENT OF THE WASHINGTON REGION

BY N. H. DARTON

Remarks upon the subject of the paper were made by W. M. Davis.

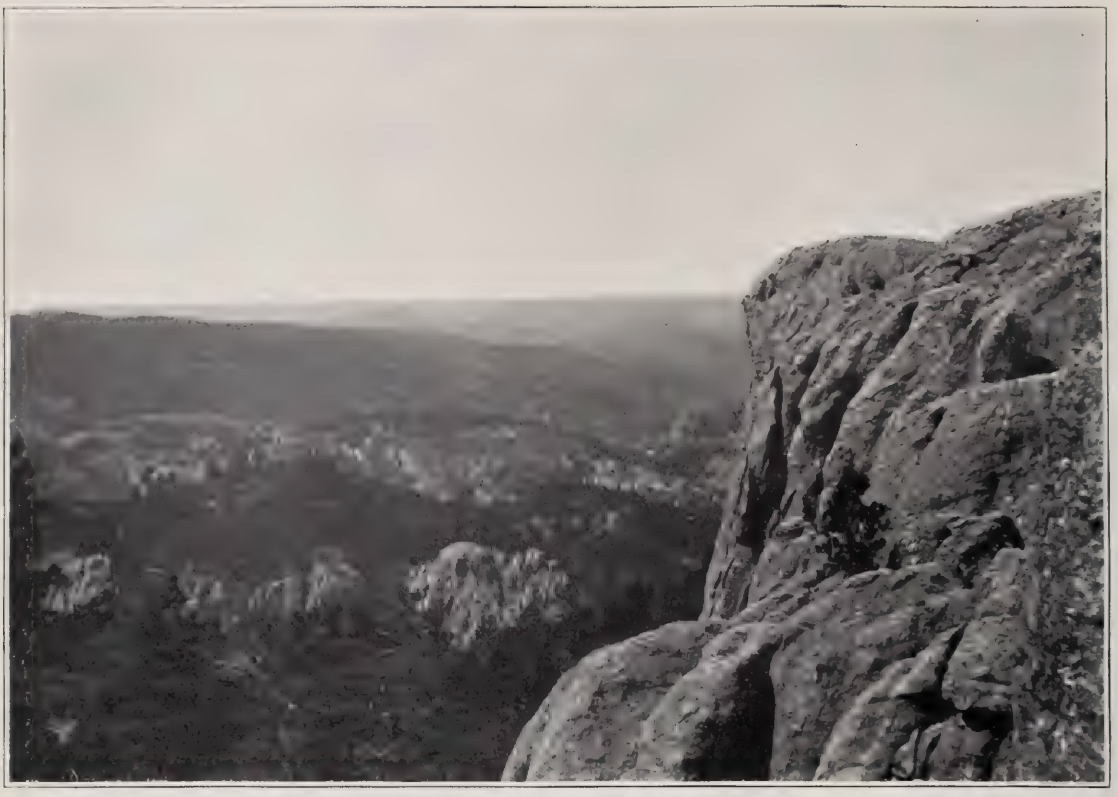

Figure 1.—View Northwestward from Summit of Harney Peak

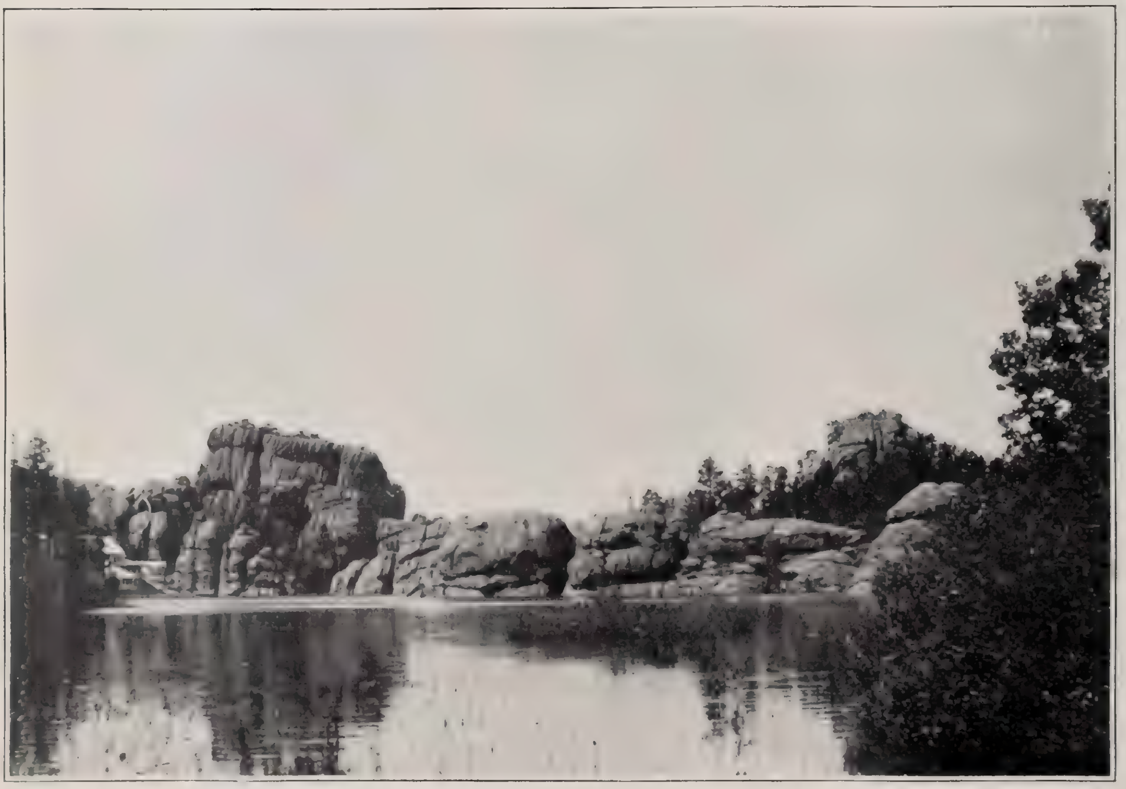

Figure 2.—Sylvan Lake, South Dakota

Artificially formed lake in southern granite area of Black Hills

SUMMIT OF HARNEY PEAK AND SYLVAN LAKE

The second paper was

EROSION FORMS IN HARNEY PEAK DISTRICT, SOUTH DAKOTA

BY EDMUND OTIS HOVEY

[*Abstract with discussion*]

The pre-Cambrian geology of the Black hills of South Dakota has been ably treated by Van Hise* before this Society, and by Newton,† Crosby,‡ Carpenter,§ and others elsewhere, and the present paper does not presume to attempt to add to the geological facts brought out by these observers. The surface features, however, of the granitic region near Harney peak are so very peculiar that the verbal descriptions of N. H. Winchell ‖ and Newton ¶ convey but an inadequate idea of the relief of the country, and a reproduction of some photographs taken last summer (1899) may not be without some value.

The so-called granite area forming the Harney Peak district and the culminating point of the Black hills is an irregular oval about 16 miles long from north to south and 10 miles wide, but it is by no means all granite. The central portion, including Harney peak, shows nothing but the coarse grained granite, the valleys between the resistant ridges being covered with soil and bearing forests of the Rocky Mountain pine up to the vertical walls of the granite ridges, so that no other rock seems to be exposed. The outer portion of the area, however, consists of numerous lenses or bosses of granite which have forced their way up through the mica-schists of the general region. The schists have suffered most from erosion and have left the granite standing in high, narrow ridges, the summits of which rise from 200 to 500 feet above the intervening valleys, and are often wholly inaccessible. The granite is intersected by numerous joint planes, and erosion has progressed in such a way as usually to produce sharp pyramidal and needle-like forms in the rock. The ends of the lenses being narrower than the middle, the terminal needles have disintegrated and worn down more rapidly than the others, and the upper portion of a vertical section is elliptical, a form which may or may not correspond with the original shape of the lense. This feature is well shown in figure 1 of plate 55, which represents the end of a ridge descending into the valley between two other ridges. That there has been no glaciation of the region is indicated by these jagged forms and the absence of grooved and polished surfaces and erratics.

Figure 1 of plate 53 shows a part of the view northwestward from the summit of Harney peak. The ridges of granite are seen projecting above the tree tops. The heavily wooded hills in the near distance are of schist. The outlook in every direction from the peak shows how intricate is the network of these lenses. Figure

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* C. R. Van Hise: The pre-Cambrian rocks of the Black hills. Bull. Geol. Soc. Am., vol. 1, 1890, pp. 203-244.

† Henry Newton, E. M., and Walter P. Jenny, E. M.: Report on the geology and resources of the Black hills of Dakota, with atlas, 4to, Washington, 1880.

‡ W. O. Crosby: Geology of the Black hills of Dakota. Proc. Boston Soc. Nat. Hist., vol. 23, 1888, pp. 488-517.

§ Franklin R. Carpenter: Preliminary report of the Dakota School of Mines upon the geology, mineral resources, and mills of the Black hills of Dakota, 1888.

‖ William Ludlow: Report of a reconnaissance of the Black hills of Dakota, made in the summer of 1874, 4to, Washington, 1875; Geological report by N. H. Winchell, pp. 21-66. Pp. 42-46.

¶ Geology of the Black hills, pp. 65-80.

2 of the same plate gives a good general idea of the jointing in the broad portion of a long granite ridge at Sylvan lake, about 4 miles south of Harney peak. The lake has been formed artificially by throwing a dam across a narrow gorge through which a small stream finds its way. It is evidently not a "rock basin." The granite here contains a large proportion of muscovite, so much in fact that the attempt has been made to exploit it commercially. This ridge is comparatively broad and the forms produced by disintegration and erosion are more rounded than they are in some other parts of the district. The most striking and interesting of the erosion forms are those to be seen in "Cathedral park," a small area about 2 miles southeast of Harney peak, where the narrow ridges of granite have been weathered into a remarkable series of jagged pinnacles, a few views of which are reproduced on plates 54, 55, and 56. The ridges now standing are divided into plates the long diameters of which are parallel with the main system of joints in the region, or about northwest and southeast. The main system of joint planes is crossed at various angles by subordinate planes of fissure. The weathering has been most extensive along the more persistent joints, and the combination has produced the almost endless variety of jagged forms which characterize the Harney Peak district. Degradation along strong fracture planes nearly at right angles to one another has produced the angular shafts in the granite which are indicated in figure 1, plate 56. These shafts are bare of fresh debris, their bottoms being well grassed over.

The pegmatitic character of some of the ridges near the outer portion of the main granitic area about Harney peak, in the Black Hills, is shown on a gigantic scale in the knoll which forms the principal working of the famous Etta tin mine. This is a mass of albite, quartz, and greenish white muscovite in which occur enormous crystals of spodumene. The rock carries a small amount of cassiterite and some columbite, and has been called "greisen," incorrectly, by the miners, on account of the presence of the tin ore. The spodumene crystals lie at all angles in the matrix, like so many great sticks of timber, and a few of them are shown in figure 2 of plate 56. One crystal that I measured roughly in the side of one of the old adits was more than 30 feet long and 30 inches wide. The crystals are crossed by numerous fissures, are bounded by imperfect planes, and all seem to lie on edge in the rock. None were observed which had been disturbed by faulting. Many were surrounded by zones of alteration products. The spodumene was thrown on the dump while the property was being worked for tin, but now it is being quarried in a small way for commercial purposes for its lithia content, the cassiterite being thrown to one side.

In the discussion which followed S. F. Emmons said:

The granite needles apparently result from the wearing away of the softer schists that once surrounded them. The schists are generally covered by surface accumulations and rarely show distinct outcrops. Inclusions of them are, however, found in the central granite mass of Harney peak, and a section is exposed in a road cutting near the hotel. With increased distance from the central Harney Peak mass the granite bodies assume a more distinctly lenticular form, and stand out more and more isolated in the forest covered region where few outcrops of rocks other than granite can be detected. On the outer edges of the area in which granite exposures are found, the granite assumes the form of flat-lying pegmatite veins dipping gently away from the Harney Peak mass.

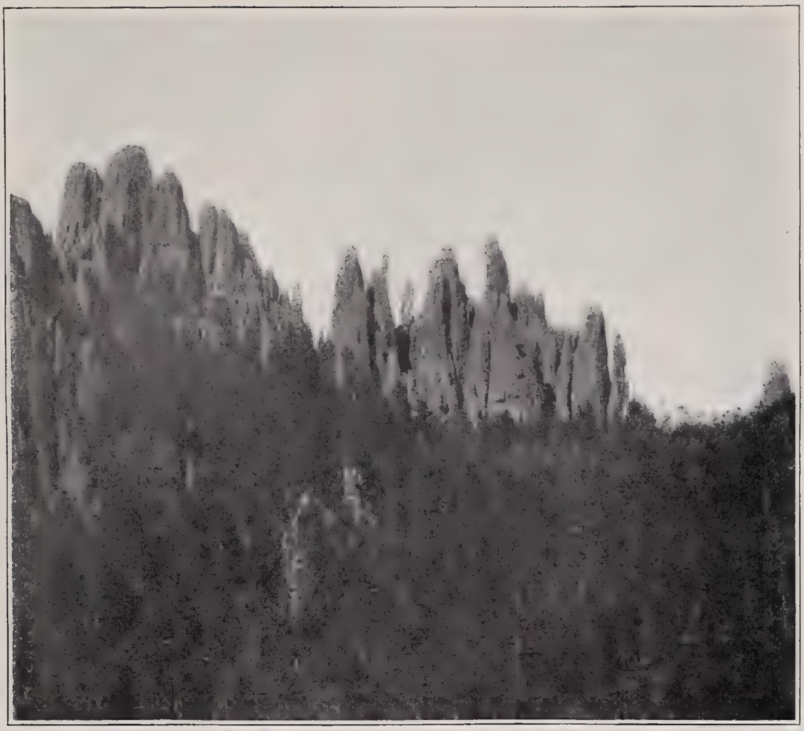

Figure 1.—The "Needles" near Harney Peak
View from south

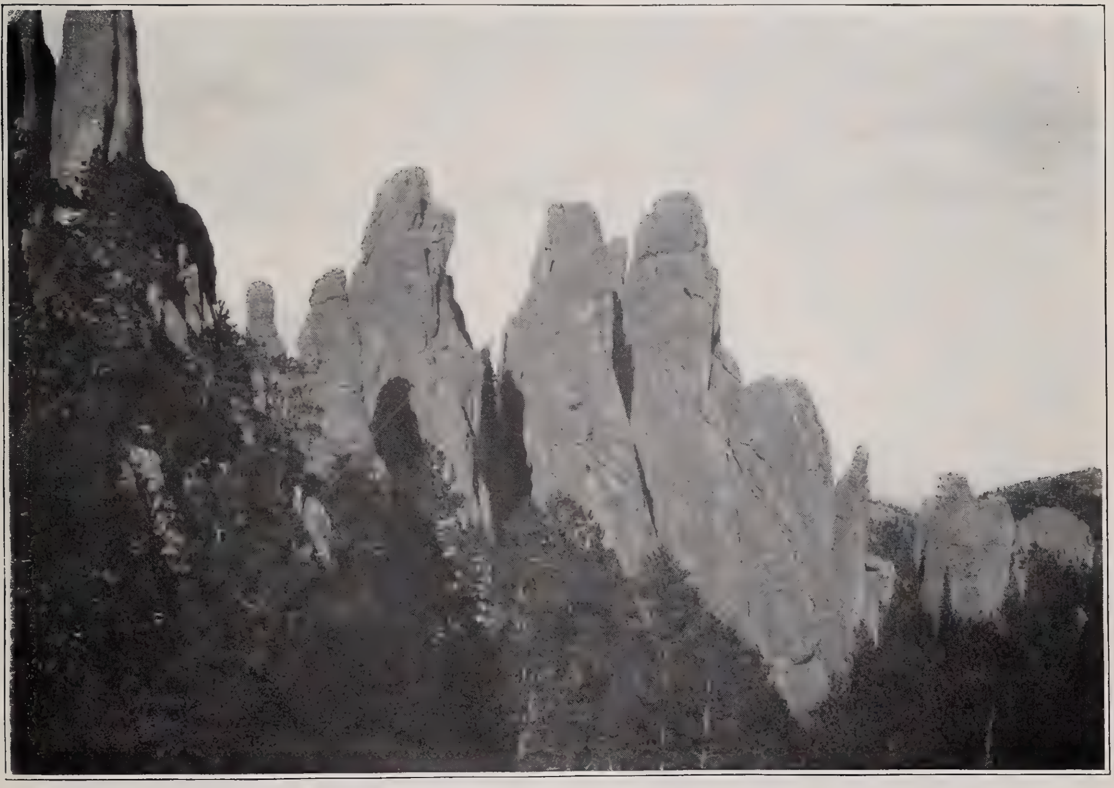

Figure 2.—The "Needles" from Southwest

THE NEEDLES

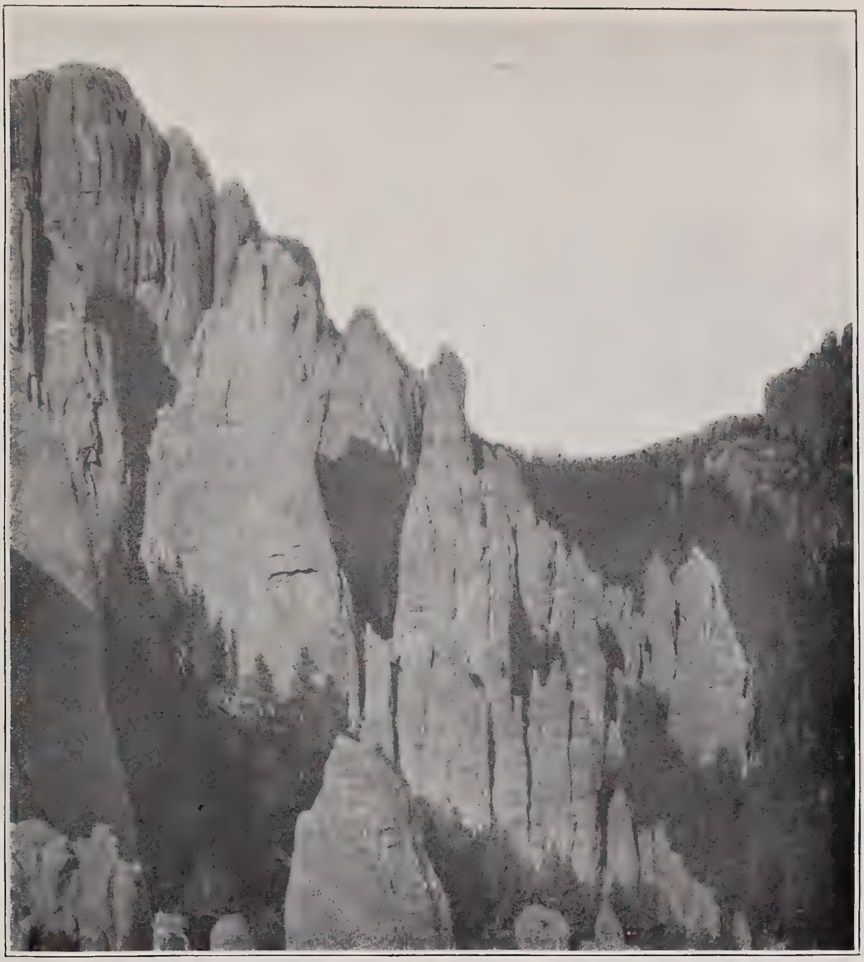

Figure 1.—Crags near the "Needles"—looking East

View shows end of a lens descending into the valley between two other lenses

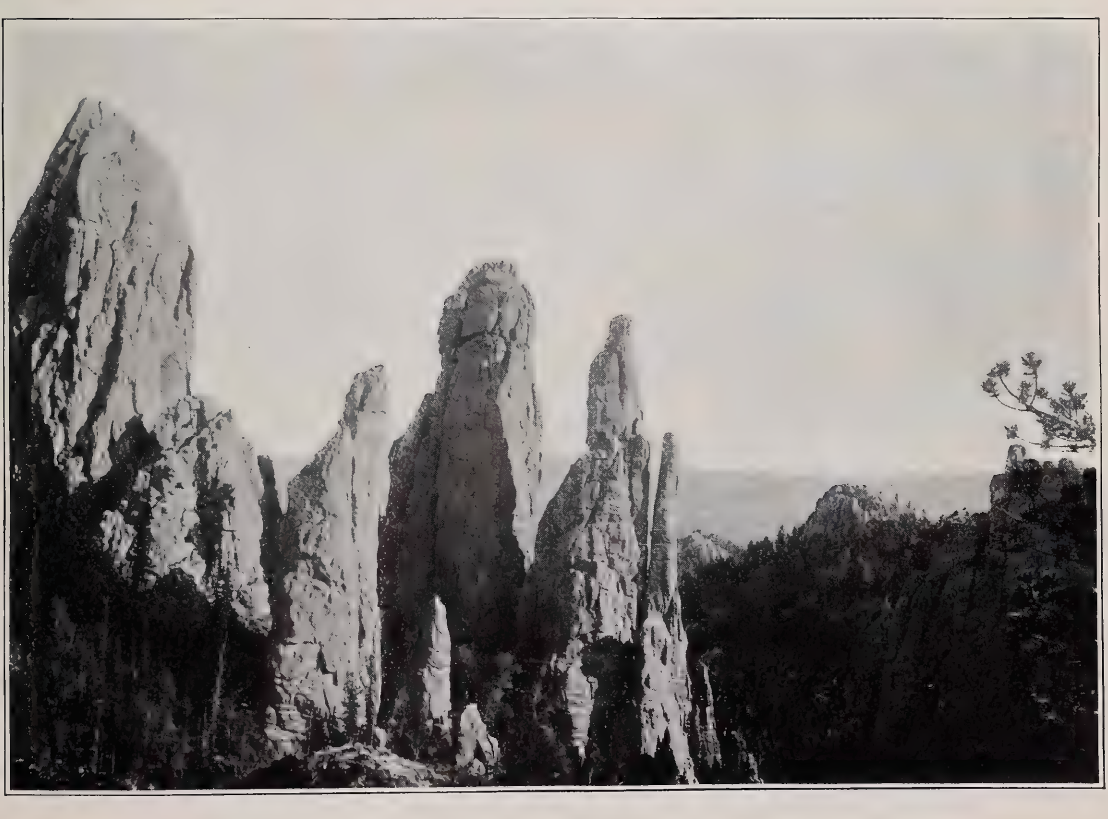

Figure 2.—Crags near the "Needles"—looking South

CRAGS NEAR THE NEEDLES

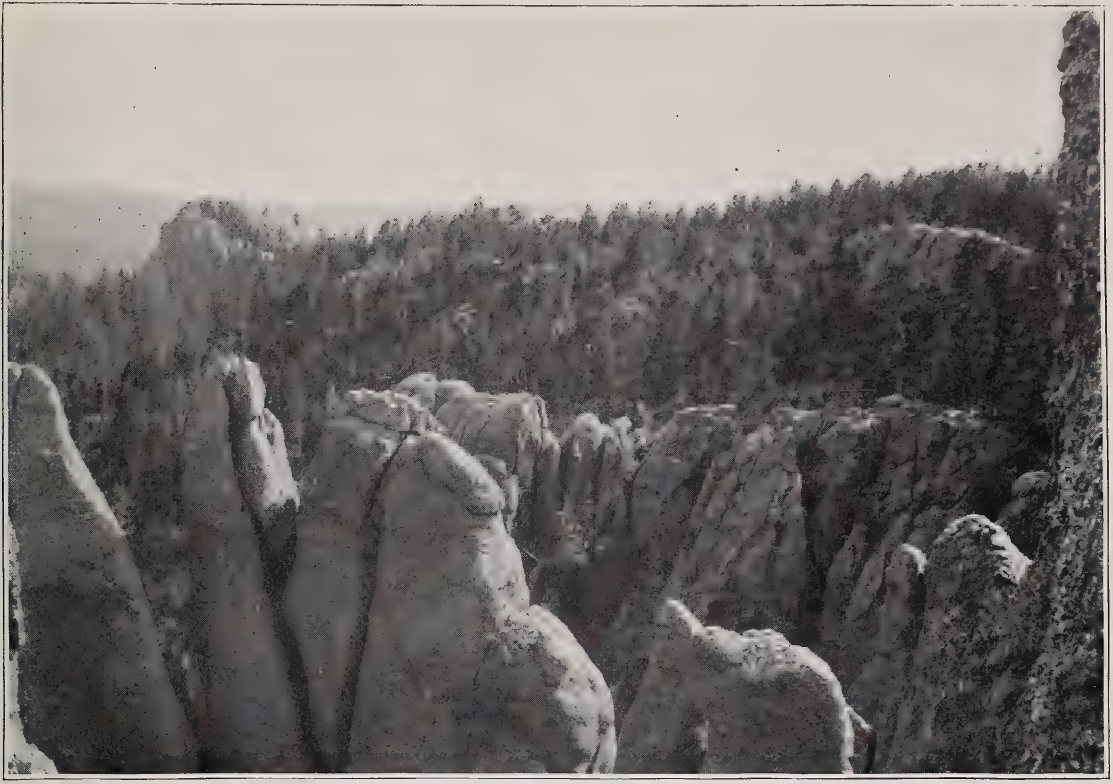

Figure 1.—Crags near the "Needles"
Looking into angular spaces made by erosion

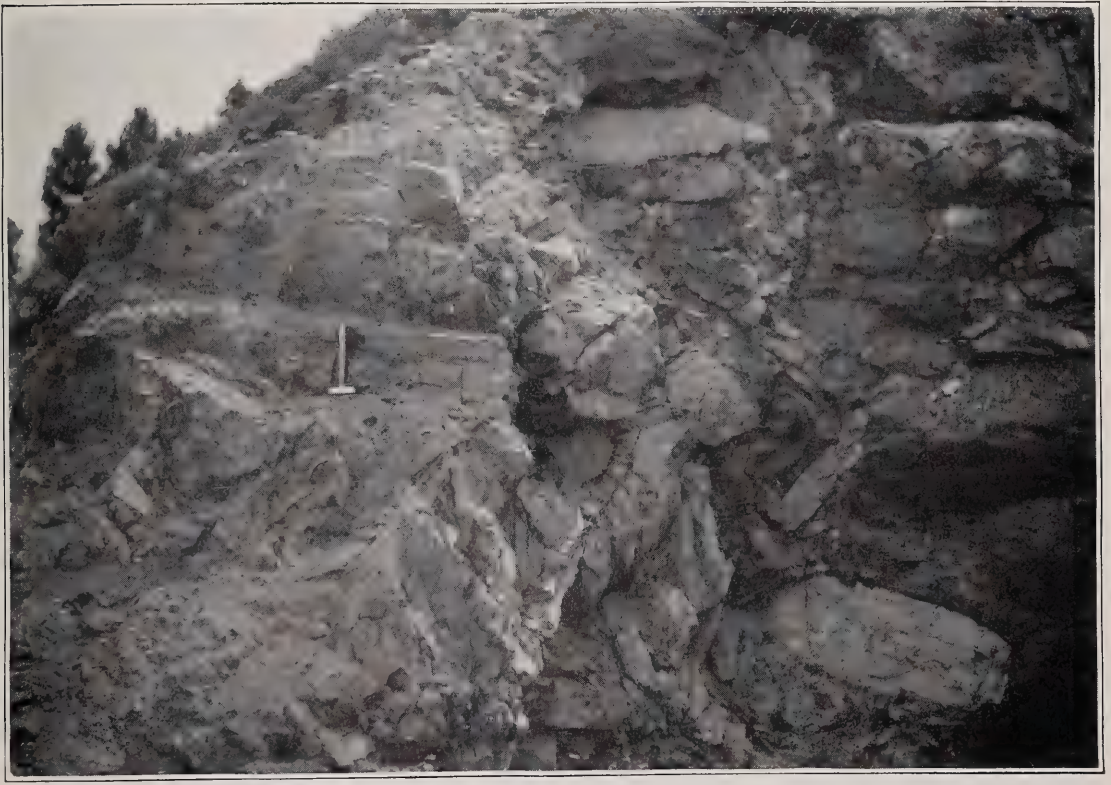

Figure 2.—Great Spodumene Crystals at Etta Tin Mine
Hammer gives standard of measure

CRAGS NEAR THE NEEDLES AND SPODUMENE CRYSTALS

Remarks were also made by J. B. Woodworth, A. C. Spencer, and the President.

The third paper was

TOPOGRAPHIC FEATURES OF OHIO

BY W. G. TIGHT

The subject was discussed by M. R. Campbell, I. C. White, and the author.

The next paper was by the same author, as follows:

DRAINAGE MODIFICATIONS IN SOUTHEASTERN OHIO

BY W. G. TIGHT

Remarks upon this paper were made by M. R. Campbell, I. C. White, and the author.

The following paper was then read:

LANDSLIDES OF THE RICO MOUNTAINS, COLORADO

BY WHITMAN CROSS

[*Abstract with discussion*]

The Rico mountains, in southwestern Colorado, are due to the erosion of a local domatic uplift. The sedimentary formations affected embrace the Algonkian, Devonian, Carboniferous, Permo-Carboniferous, Juratrias, and Cretaceous. Many intrusive dikes, sheets, and small laccoliths of diorite—or monzonite—porphyry occur in this complex. A large monzonite stock penetrates all rocks above mentioned. Intense and complicated faulting has taken place in the heart of the uplift, and there has been a great amount of mineralization, forming argentiferous ore bodies of many types.

Landslides, occurring in a recent geological epoch, are very prominent features of the local geology. These landslide areas will be described, the relation of the phenomena to other elements of the geological history will be discussed, and hypotheses of their origin set forth in the paper when printed.

In the discussion of the subject of Mr Cross' paper, Mr J. B. Woodworth said in substance:

Landslips occur near the head of Warm Springs creek, in the Gravelly range in Montana. Here the movement has taken place on westward dipping water-bearing Cretaceous strata. The slides simulate small moraines, enclosing lakelets, and might be mistaken for glacial deposits, which also occur in the vicinity.

Mr George Otis Smith spoke as follows:

In the Mount Stuart quadrangle in Washington the occurrence of landslides is the rule rather than the exception. Professor Russell first called attention to these phenomena in central Washington, and the subsequent mapping of this quadrangle has shown that landslides occur in every formation except the granodiorite. They vary in extent from blocks a few yards across to areas of slipped rock-masses that measure miles. These landslides also vary much in age, some showing terraces carved upon them in early Pleistocene time, others so fresh that vegetation has not yet gained a foothold, while cracks at some distance back from the escarpments show the beginnings of future landslides.

Remarks were also made by W. M. Davis and W. H. Niles.

The last paper presented on Wednesday was the following:

FAULT SCARP IN THE LEPINI MOUNTAINS, ITALY

BY W. M. DAVIS

This paper is printed as pages 207–216 of this volume.

Session of Wednesday Evening, December 27

The Society convened at 8.30 o'clock for the presidential address, which was read with the aid of lantern views. The address was entitled

THE TETRAHEDRAL EARTH AND ZONE OF THE INTERCONTINENTAL SEAS

BY THE PRESIDENT, BENJAMIN K. EMERSON

The address is printed as pages 61–106 of this volume.

Session of Thursday, December 28

The Society convened at 9.30 o'clock a m, the President in the chair.

The report of the Council was taken from the table and adopted without remarks.

Doctor E. O. Hovey reported that the Auditing Committee had found the accounts of the Treasurer correct, and the Society adopted the report.

The Committee on Photographs submitted its report as follows:

TENTH ANNUAL REPORT OF COMMITTEE ON PHOTOGRAPHS

The committee have to report the addition of 35 views, bringing the full number in the collection up to 1,913. A list of these is given below.

The number of accessions, it will be noted, is comparatively small. This is due in part to the apathy of the members of the Society and in part to the fact that the chairman has not felt it advisable to continue longer to accept without discrimination all that were offered.

The collection is already so large that its proper care and exhibition on desired occasions is a somewhat serious matter, and it is felt that the wants of the Society will be best subserved by selecting only such views as illustrate to advantage some particular phase of geological phenomena.

The chairman calls attention of members to the fact that it is impossible for the committee to know in all cases what material is available, and asks that those having such will communicate promptly with him, and, if possible, send in their donations a month prior to the December meeting.

The committee asks a continuation of the appropriation of $15 for expenses during 1900.

Respectfully submitted. George P. Merrill,
Chairman.

Presented by the United States Geological Survey

One photograph, 6 by 8 inches, by C. D. Walcott

1879. Mouth of Fountain geyser, shortly before eruption, Yellowstone National park, 1898.

Fifteen photographs, 5 x 7 inches, by G. K. Gilbert

1880 (281). Drift-strewn surface, laid bare within twenty years by the Hugh Miller glacier, Glacier bay, Alaska.
1881 (333). Push moraine of Crillon glacier, Alaska, showing disturbed forest.
1882 (356). Push moraine, made probably in 1892 by the Columbia glacier, Alaska.
1883 (370) Section of moraine ridge on Hidden glacier, Alaska, showing protection of ice from ablation by a veneer of drift.
1884 (371). Freshly formed kettle hole in gravel derived from the Hidden glacier, Alaska.
1885 (372). Gravel waste plain of the Hidden glacier, Alaska, showing incipient kettle hole.
1886 (395). Cleavage in Yakutat shales, near Kadiak, Alaska; more nearly vertical in argillaceous (darker) strata than in arenaceous (paler) strata.
1887 (399). Drowned foreland, Kadiak, Alaska.
1888 (470, 471). Delta in Gastineau channel at Juneau, Alaska, as seen at low tide.
1889 (506). Dunes, Biggs, Oregon.
1890 (507). Dunes, Biggs, Oregon.
1891 (509). Dunes, Biggs, Oregon.
1892 (513). Wind-made ripples on dune, Biggs, Oregon.
1893 (514). Wind-made ripples on dune, Biggs, Oregon.
1894 (527). Spheroidal structure in volcanic rock. One mile east of Cascade locks, Oregon.

Seventeen photographs, 8 x 10 inches, by N. H. Darton

1895 (637). Big Badlands of South Dakota, east side of Cedar draw, Washington county. Columns capped by sandstone, White River formation.

1896 (643). Big Badlands of South Dakota, head of Cedar draw, Washington county. Erosion forms in Titanotherium sands.

1897 (648). Big Badlands of South Dakota, east side of Cedar draw, Washington county. Columns of sandy clay capped by sandstone.

1898 (647). Big Badlands of South Dakota. A portion of the divide between Battle draw and Cedar draw. Oreodon beds of White River formation.

1899 (642). Big Badlands of South Dakota, looking across head of Battle draw, Washington county, South Dakota. Titanotherium beds in middleground, overlain by Oreodon beds on the higher slopes. Late afternoon view.

1900 (585). Little Sundance dome east of Sundance, Wyoming. Purple limestone and underlying beds uplifted by a laccolite.

1901 (595). Concretions in Laramie sands, Weston county, Wyoming.

1902 (673). Fossil tree in Lower Cretaceous sandstone southwest of Minnekahta station, South Dakota. Southern Black hills.

1903 (672). Thermal spring at Cascade springs, South Dakota. Black hills.

1904 (618). Granite needles near Harney peak, South Dakota. Black hills

1905 (619). Granite needles near Harney peak, South Dakota. Black hills, near view. Telephoto.

1906 (622). "Hogbacks" of Dakota sandstone on south side of Buffalo gap, Black hills, South Dakota, looking southwest.

1907 (670). Grindstone quarry in Dakota sandstone north of Edgmont, South Dakota. Southern margin of Black Hills uplift.

1908 (593). Sink-hole in Minnekahta limestone east northeast of Cambria, Wyoming.

1909 (587). A typical tepee butte, Weston county, Wyoming, due to limestone lense filled with *Lucina occidentalis,* in Pierre shale.

1910 (651). Minerva terrace, Mammoth Hot springs, Yellowstone park, Wyoming.

1911 (667). Paint pots near Fountain hotel, Yellowstone park, Wyoming.

Presented by the United States National Museum

Two views, 7½ by 9½ inches, by George P. Merrill

1912, 1913. Two photographs of faulted sandstone in National Museum. Samples collected by N. H. Darton.

The report of the Photograph Committee was adopted and the appropriation of $15 voted.

The ninth annual report of the Photograph Committee for the year 1898 (see the Bulletin, volume 10, page 463) was presented by J. F. Kemp, and adopted.

The chairman of the Committee on Photographs, Mr George P. Merrill, submitted his resignation, desiring to be relieved after five years of service. After some remarks of appreciation of the successful labors of the chairman, his resignation was accepted. The remaining members of the committee, J. K. Kemp and W. M. Davis, also resigned, and their resignations were accepted.* The Society then elected N. H. Darton as the Committee on Photographs.

The Secretary read the following letter concerning the

ORGANIZATION OF THE CORDILLERAN SECTION

Berkeley, California, *March 29, 1899.*

To the Council of the Geological Society of America.

Gentlemen: As a result of the uneven distribution of population in North America, the convenience of the majority of the Fellows determines that the meetings of the Society shall usually be held at the greater centers of population in the eastern part of the United States or Canada. Fellows of the Society resident on the Pacific slope can attend such meetings only at a great expenditure of time and money, and are thus placed at a disadvantage; they are, indeed, practically deterred from participating in the chief benefit which arises from membership in the Society, namely, personal intercourse with fellow-geologists gathered in meetings for scientific discussion.

We, the undersigned Fellows of the Society, resident on the Pacific slope, therefore respectfully propose that the Society, recognizing the great extent of the country and the geographical distribution of its Fellows, amend its constitution so as to permit of the organization within the Society of a section embracing Fellows resident in the western part of the country who desire to meet for the reading of papers, scientific discussion, and social intercourse at times and places independent of the stated meetings of the Society.

We therefore respectfully request your honorable body to formulate and submit to the Society at its next regular meeting an amendment to the constitution having this end in view.

Very respectfully,

(Signed) Joseph Le Conte.
E. W. Hilgard.
R. H. Loughridge.
John C. Merriam.
Andrew C. Lawson.
J. C. Branner.
E. W. Claypole.
H. W. Fairbanks.

The Secretary stated that some correspondence had passed between Professor Lawson and himself previous to the meeting of the Council; that the Council had considered the matter and recommended to the Society the authorization of the Cordilleran Section under such rules and conditions as the Council may prescribe; also that the Pacific Coast Fellows were planning to hold a meeting at San Francisco, Friday and Saturday, December 29 and 30.

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* The Committee on Photographs was originally appointed in August, 1890, and consisted of J. S. Diller, chairman, J. F. Kemp, and W. M. Davis. In December, 1894, George P. Merrill succeeded Mr Diller as chairman.

Mr. Bailey Willis moved the adoption of the Council's recommendation, favoring the action from a personal knowledge of the circumstances. The subject was debated at length. No one spoke in positive opposition, but some Fellows expressed doubt and anxiety as to the effect of the movement. The recommendation of the Council was adopted.

The matter of the correct pronunciation of "Cordilleran" was brought up by W. M. Davis, and it was, by vote, referred to the Council for subsequent report to the Society.

Mr C. D. Walcott read a letter from the First Vice-President, Dr George M. Dawson, expressing regret at his inability to attend the meeting, and the Secretary presented a letter of similar import from Professor N. H. Winchell, Second Vice-President elect.

The first paper of the scientific program was entitled

DEPOSITS OF CALCAREOUS MARL IN MICHIGAN

BY ISRAEL C. RUSSELL

Remarks were made by J. F. Kemp and J. M. Clarke.

The second paper was

GLACIAL ORIGIN OF OLDER PLEISTOCENE IN GAY HEAD CLIFFS, WITH NOTE ON FOSSIL HORSE OF THAT SECTION

BY J. B. WOODWORTH

The subject of the paper was discussed by W. G. Tight and the author. The paper is printed as pages 455 to 460 of this volume.

The third paper was by the Secretary, and consisted chiefly of a series of lantern views.

BEACH STRUCTURES IN MEDINA SANDSTONE

BY H. L. FAIRCHILD

Remarks upon the paper were made by C. W. Hayes and H. S. Williams.

The fourth paper was the following:

GLACIAL EROSION IN THE AAR VALLEY

BY ALBERT P. BRIGHAM

[*Abstract with discussion*]

The writer spent three days of August, 1899, in the Aar valley above Meiringen. The powerful abrasion of the crystalline rocks about the Grimsel hospice has been described by Agassiz and others. This is seen in the great dome, which rises to a height of 350 feet between the Grimsel lakes on the south and the torrent of the Aar on the north. It also appears in the north wall of the gorge at this point, in the rôches moutonnées of the Grimsel pass, and, indeed, everywhere, save on the recently weathered and frost-riven summits of the surrounding mountains.

Attention was, however, specially directed to a series of rock basins, of which several lie between the Aar glacier and the Handeck fall, a distance of about 7 miles. Nearly all of them are now filled with torrential debris, brought from the glacier; at least they are filled up to the plane to which the rim of the original basin has been cut by the powerful existing stream.

The first of these basins extends from the front of the lower Aar glacier eastward for more than a mile, and is, on the average, one-fourth of a mile wide. It is impossible to say how far westward the basin would be found to continue were the glacier to disappear. It seems probable that it may extend several miles, or nearly to the Abschwung, when we take account of the long existence, strong descent, sturdy tributaries, and consequently vigorous work of such an ice-stream. The present floor of this aggraded basin is morainic about the glacier front for a short distance, but for the most part is a flat ground of coarse gravel and cobblestones, traversed irregularly by the wandering river as it issues from its subglacial course. Near the Grimsel hospice a barrier of the bed rock, powerfully glaciated and about 100 feet high, reaches out from the south wall of the valley to the recently cut gorge which carries the stream under the north wall. Between this barrier and the hospice is another floor of an aggraded basin, the Spitalboden, about one-third of a mile long, followed by the rocky rim, over which the river enters the narrow gorge, below the post road and north of the hospice.

About one mile below this point the river, descending rapidly, issues from the gorge upon the Ratherichsboden, an alluvial floor similar to those already described. It is about one-half mile long and, like the others, marks a section of the valley in which a deep and broad gouge was made by the glacier. At the northern end of Ratherichsboden the river enters a V-shaped gorge between spurs which close in from either side of the valley. Both of these are strongly and beautifully rounded by glacial abrasion, and immediately above them Bächlisbach enters on the west and Gerstenbach on the east. The localities here given all appear on sheets 597 (Guttannen) and 490 (Obergestelen) of the Swiss topographic survey, but the contouring and hachures give but a poor idea of the striking alternation of lobe like basins with V-shaped gorges, which it is the object of this paper to notice. The walls of the gorge below Bächlisbach, as of some others of the series, are glaciated nearly to the bottom.

Passing this gorge a fourth basin appears, with lofty and strongly scored slopes. This basin contains but a small floor of alluvium, and indicates but slight excavation below the level of the stream as it passes into the next constricted section. This gorge, also V-shaped, with glaciated walls, leads down to the spacious basin above the famous Handeck fall. The greater part of the basin is now floored with wide-spreading fans, built by torrents descending from the west. Opposite Handeck we have lateral spurs closing in, though not so narrowly as below Rätherichsboden. Between Handeck and Guttannen, and also between Guttannen and Innertkirchen, similar irregularities or alternations of glacial excavation occur, but none is so conspicuous as those already described. The last named village lies on a fine floor of an ancient lake, a vale well known to travelers who have visited the great gorge of the Aar above Meiringen. It is not the object of this paper to describe this locality, except to observe that we have here apparently a case of erosion similar to those seen about the Grimsel. This basin has been described as a product of glaciation, though some Swiss observers, notably Heim, hold otherwise.

In general, the basins appear to mark points of effective ice-work, and seem, in several cases at least, to lie at the foot of what must have been a sharp descent of the ice, and therefore a place of strong abrasion. The Grimsel lakes occupy similar basins, and seem to have escaped the filling to which the others have been subjected by being left out of the track of the debris-laden torrent.

Below the lower Aar glacier, on the south side, a stream descends over the steep cliff face, carrying the waters of the upper Aar glacier. The lateral valley enters its principal some hundreds of feet above the floor of the latter, and thus is a typical case of the hanging valley, interpreted by Davis and others as due to more effective glacial erosion in the trunk valley, in contrast with the law of ordinary stream and valley development, by which the chief and lateral valleys are graded to the same level at the point of union. Similar hanging valleys enter from east and west at Innertkirchen. Another enters the Rhone valley from the east, immediately adjoining the fall of the Rhone glacier, and other cases may be seen along the same valley, between Visp and Martigny.

In discussion of Professor Brigham's paper, W. M. Davis showed some lantern views illustrating the topic, and made the following remarks:

The discordance between the depth of a main valley and that of its tributaries, as shown by Professor Brigham in the case of the Aar, is very striking in the glaciated areas of the Alps. No locality exhibits the discordance better than the valley of the Ticino, followed by the Saint Gotthard railway southward from the great tunnel into Italy. The main valley is not a gorge, but a broad trough, gravel-floored, and with steep, cliff-like walls for several hundred feet of height, above which the mountain slopes flare out, as if they were the upper parts of a more ordinary V-shaped valley. The side valleys are V-shaped in cross-section, and the streams from them cascade into the main valley, thus repeating the features shown by Professor Brigham at several points in the valley of the Aar. Although most writers on glacial erosion have given little importance to the discordance of main and side valleys in glaciated regions, and although the discordance is explained by so experienced an observer as Heim as a result of normal river erosion after a period of uplift (the river of the main valley outstripping the streams of the side valleys in the work of valley deepening and widening), the greater depth and breadth of the main valley than of the side valleys is by several Alpine observers not only held to be beyond explanation by other than glacial action, but to be in itself an excellent index and measure of such action. It seems at first as if the discordant floors of glaciated valleys were abnormal. They do not appear to fall under the general relation—the accordant levels of main and tributary valley floors—that was employed at the beginning of the century by Playfair as one of the best proofs that valleys are eroded by the rivers that occupy them. But a closer examination shows that glaciated valleys are not abnormal in this respect. Glaciers are slow moving streams; the cross-section of their bed is a considerable part of the valleys which they occupy. Water streams are nimble; the cross-section of their beds is but a small part of their valleys. Moreover, river beds are seldom visible, being usually occupied by water; but today the beds of former glaciers are evacuated by ice, and are so plainly laid bare that they are generally regarded as a part of the valleys in which they have been excavated. The water surface of rivers and the floor of their valleys are graded to accordant junction, but if the water were dried away the bed of a small branch stream would be found distinctly shallower than that of a large main trunk; a distinct break might occur between the level of the two. So with valleys that are now occupied by glaciers. The surface of the confluent ice-streams and the slopes of the valleys above ice-level are normally related to each other, but the beds of the smaller ice-streams are not worn so deep as that of the larger ones, and when the ice disappears the discordance of the larger and smaller glacier beds may become a striking feature of the landscape. The water streams which then perform the drainage of the region may for a considerable post-glacial period possess strong cascades where the side valleys open on the main valley walls.

G. K. Gilbert said

That glaciation was not the only process causing discordance between main valleys and their tributaries, and cited the canyon of the Virgen river through Juratrias sandstones and the canyon of the Columbia river through the Cascade range as instances of trunk streams corrading so rapidly as to outstrip their feeble affluents and leave the truncated gorges of the latter stranded high in the canyon walls; but such a process does not produce the broad-floored hanging valleys of glaciated regions, and the elevation of these valleys he believed to record the difference between the powerful action of trunk glaciers and the feebler action of side glaciers. He had been greatly impressed, years ago, by the magnitude of the glacial excavation indicated by such phenomena in the high Sierra, and last summer had found the coast of Alaska replete with similar evidence. After sailing for weeks through Alaskan fiords and observing scores of hanging valleys, he had come to regard their occurrence as diagnostic of the former extent of glaciation, and had used them with confidence as criteria for the discrimination of glaciated districts.

H. W. Turner spoke as follows:

The hanging valleys of the Sierra Nevada are considered by some writers as evidence that the canyons were formed by glacial erosion, but in some portions of the range we will find these hanging valleys bordering canyons which never contained glacial ice. Such an example is on the Bidwell Bar quadrangle in the northern Sierra Nevada. The canyons of the north and middle forks of the Feather river, in this quadrangle, are largely in granite. They are deep and rugged, one portion of the North Feather canyon being nearly a mile deep, as measured from the highest part of the plateau to the east. The side streams enter these canyons from hanging valleys over precipitous slopes in cascades and falls, one of which has a height of 450 feet or more. While small glaciers existed during the Glacial period on the plateaus about these canyons, there is no evidence that glacial ice ever occupied any portions of the main canyons. As is well known, the whole range during the Tertiary had been greatly worn down, so that broad shallow valleys were characteristic of it. When late in the Tertiary or in the early Pleistocene the range was somewhat sharply uplifted, the streams were given new vigor. The larger streams cut much more rapidly than the smaller ones, and formed the present deep river canyons, while many of the smaller streams occupying depressions inherited from the Tertiary have cut much less rapidly, and hence these depressions remain as hanging valleys. It is quite certain that the entire range was subjected to the same influences, and it hence seems logical to suppose that the main topography of the range was carved in early Pleistocene time very largely by water action, and in the glaciated region these water-formed valleys and canyons were very considerably modified by the glacial ice. The Glacial period of the Sierras can be placed in the middle or later Pleistocene, and is relatively shorter than the period of erosion which preceded it, and which I designate, following Le Conte, the Sierran period.

Remarks were also made by I. C. Russell, J. J. Stevenson, A. C. Spencer, I. C. White, S. F. Emmons, the President, and the author.

President Emerson read an invitation from Professor Cleveland Abbe inviting the Fellows to his home.

The following two papers were read by their author:

MOVEMENT OF GLACIERS

BY HARRY FIELDING REID

STRATIFICATION AND BANDED STRUCTURE OF GLACIERS

BY HARRY FIELDING REID

Immediately following the reading of Doctor Reid's papers the Society adjourned for luncheon. Upon reassembling, the discussion of the papers was given place, and remarks were made by Bailey Willis and the President.

The first paper of the afternoon session was by the Secretary, presented briefly, with aid of lantern views.

A CHANNELED DRUMLIN

BY H. L. FAIRCHILD

The second paper was entitled:

UPPER AND LOWER HURONIAN IN ONTARIO

BY A. P. COLEMAN

Remarks were made by C. D. Walcott. The paper is printed as pages 107–114 of this volume.

The third paper was

CAMBRIAN SYSTEM OF THE ATLANTIC PROVINCE

BY C. D. WALCOTT

Remarks were made by J. F. Kemp.

The four papers following were read and discussed together. By request of the author Mr Schuchert's paper was read by J. M. Clarke.

LOWER DEVONIC ASPECT OF THE LOWER HELDERBERG AND ORISKANY FORMATIONS

BY CHARLES SCHUCHERT

This paper is printed as pages 241 to 332 of this volume.

SILURIAN-DEVONIAN BOUNDARY IN NORTH AMERICA

BY HENRY S. WILLIAMS

This paper is printed as pages 333 to 346 of this volume.

SILURO-DEVONIAN CONTACT IN ERIE COUNTY, NEW YORK

BY A. W. GRABAU

This paper is printed as pages 347 to 376 of this volume.

DEVONIAN STRATA IN COLORADO

BY ARTHUR C. SPENCER

In discussion of the four papers remarks were made by J. M. Clarke, H. S. Williams, and C. H. Hitchcock.

No evening session was held, but the Fellows, with invited guests, partook of the annual dinner at the Hotel Raleigh.

Session of Friday, December 29

COUNCIL'S RECOMMENDATIONS CONCERNING GEOLOGICAL CONGRESS DELEGATES AND COMPENSATION OF SECRETARY AND EDITOR

Two recommendations from the Council were presented:

1. That a committee, consisting of the President, First Vice-President, and Secretary for 1900, be empowered to name delegates to the Paris International Geological Congress.

2. That the annual allowances to the Secretary and Editor be increased to $500 and $250 respectively.

The two recommendations were adopted.

On motion of J. J. Stevenson, it was voted to authorize the Secretary to send by telegraph the greeting of the Society to the Cordilleran Section, convening this day in San Francisco.

The first paper was then read:

STRATIGRAPHY OF THE POTTSVILLE SERIES IN KENTUCKY

BY MARIUS R. CAMPBELL

Remarks were made by David White, I. C. White, W. M. Davis, J. J. Stevenson, and Bailey Willis.

The second paper was

RELATIVE AGES OF THE KANAWHA AND ALLEGHANY SERIES AS INDICATED BY THE FOSSIL PLANTS

BY DAVID WHITE

Remarks were made by I. C. White, M. R. Campbell, J. J. Stevenson, and the author.

[DISCUSSION.]

H. S. Williams remarked

That the case of the Catskill formation was analogous, and favored the interpretation given by Doctor White. It is known that the Catskill sedimentation at its extreme eastern extension is much lower in the section than it is a hundred miles farther west, in central New York-Pennsylvania, and on reaching the western limits of these states the marine Chemung faunas follow on up to the very base of the Carboniferous, with no sign of the Catskill rocks or fauna. Where the Catskill is fully developed, in eastern New York, the Chemung is either entirely wanting, so far as its marine fauna is concerned, or its fossils appear sparsely in the midst of the coarse sands of Catskill type. As low as the horizon of the Hamilton fauna the sedimentation assumes the arenaceous and sometimes the reddish character of the typical Catskill rocks.

Also, on general principles, the very fact that difference in the nature of the deposits is determined by the motion of the waters bearing the sediments makes it necessary to assume that at any particular point of time the deposits made at one place could not continue to be the same for any great distance in the direction away from the shore from which the sediments came. Hence the fact of the continuation of the identical kind of sedimentation for hundreds of miles in extent, unless assumed to be parallel to a uniform shoreline, would indicate that the formation was younger at one end than the other, to be accounted for by the gradual rising of the bottom relative to the water surface, and thus the progression of the shore-line toward the younger end of the line.

This same cause of the shifting of the sediments, namely, gradual elevation, would also be expressed in shifting of faunas which are known in modern seas to be closely adjusted to the conditions of depth.

One should expect to find, therefore, considerable shifting of faunas when the sediments are near-shore accumulations, and a close study of the geographical distribution of fossil faunas has convinced me that within a hundred miles it is quite possible to see the same chronological part of a section represented by very divergent faunas. An example may be cited in the case of Portage fauna of the Genesee River section, which in the Cayuga Lake section is represented by a very different fauna, the Ithaca fauna, and above both of them comes the typical Chemung fauna.

The paper is printed as pages 145 to 178 of this volume.

The third paper was

NEWARK FORMATION OF THE POMPERAUG VALLEY, CONNECTICUT

BY WILLIAM HERBERT HOBBS

Following the presentation of this paper the Society adjourned for luncheon. On reassembling, another paper by Professor Hobbs was read, as follows:

THE RIVER SYSTEM OF CONNECTICUT

BY WILLIAM HERBERT HOBBS

The two papers were discussed together, and the following Fellows took part: The President, H. B. Kümmel, J. P. Iddings, J. F. Kemp, W. M. Davis, R. D. Salisbury, H. W. Turner, and the author.

The next paper was entitled

JURASSIC ROCKS OF SOUTHEAST WYOMING

BY WILBUR C. KNIGHT

Remarks were made by S. F. Emmons, H. W. Turner, W. H. Weed, and Bailey Willis. The paper is printed as pages 377 to 388 of this volume.

The following paper was then read:

POTOMAC AND CRETACEOUS IN THE CAPE FEAR SECTIONS

BY J. A. HOLMES

Remarks were made by W. B. Clark, N. H. Darton, G. B. Shattuck, and T. W. Stanton.

The last two papers of the day were read by the same author:

MESOZOIC STRATIGRAPHY OF BLACK HILLS OF SOUTH DAKOTA

BY N. H. DARTON

TERTIARY SHORELINES AND DEPOSITS IN THE BLACK HILLS

BY N. H. DARTON

No evening session of the Society was held, but the Fellows of the Society attended, by invitation, a reception of the Washington Academy of Sciences at the Columbian University, preceded by a meeting of the Academy, at which reports were presented from members of the Harriman Alaskan Expedition.

SESSION OF SATURDAY, DECEMBER 30

A recommendation of the Council was presented, that the rule (By-laws, chapter 1, section 1) requiring persons elected as Fellows to qualify within three months be suspended in the case of Mr A. H. Brooks, who had been prevented by serious illness from qualifying within the stated time. The recommendation was voted.

The first paper presented was

TERTIARY GRANITE IN THE NORTHERN CASCADES, WASHINGTON

BY GEORGE OTIS SMITH AND W. C. MENDENHALL

Remarks were made by S. F. Emmons. The paper is printed as pages 223 to 230 of this volume.

The second paper was

CONTINENTAL DEPOSITS OF THE ROCKY MOUNTAIN REGION

BY W. M. DAVIS

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THEORY OF TERTIARY LAKES

Since the early days of our western governmental surveys, geologists have heard much of the remarkable series of fresh-water deposits in the Rocky Mountain region. Hayden, Marsh, Cope, King, Powell, Dutton, and other observers of more recent years have united in describing these deposits as of lacustrine origin, and all their reports abound with allusions to the great lakes that characterized the Tertiary chapter in the development of our western territory. We may read, for example, statements as emphatic as the following: "I know of no more impressive and surprising fact in western geology than the well attested observation that most of the [western mountainous] area has been covered by fresh-water lakes. . . .

The marvel is not in the fact that here and there we find the vestiges of a great lake, but that we find those vestiges everywhere. The whole region, with the exception of the mountain platforms and the preexistent mainlands, has passed through this lacustrine stage." *

The occurrence of numerous lakes is made by the same author the basis of inferences concerning Tertiary climate: "We know that the Miocene climate of the West was moist and subtropical. This is indicated by the great extent of fresh-water lakes in some portions of the West, their abundant vegetable remains, and the exuberance of land life." † Another author of great experience in the Rocky Mountain region wrote that the preservation of numerous vertebrate fossils was "probably, without exception, due to their entombment beneath the waters of the great fresh-water lakes which existed in this [Colorado] region during Mesozoic and Cenozoic time." ‡

From the first recognition of the Pliocene of the Great plains and its interpretation as a lacustrine formation, it has been taken to date one of the broad uplifts by which the Rocky Mountain region has gained its present height, for "the inclined plane of the whole system of the Great plains received its slope by mechanical tilting subsequent to the deposition of the Pliocene strata." §

Again, "movements of elevation are indicated by both Tertiary and Pleistocene deposits that have a lacustrine origin, since the present elevation of the plains region, which shows an average descent in round numbers of 10 feet to the mile from the foothill region to the valleys of the Missouri and Mississippi, would not admit of the holding of lake waters on its surface." ‖

The Tertiary lakes of the Rocky Mountain district have become stock subjects of geological teaching, if one may judge by the unqualified statements concerning them in the text-books generally in use. Dana, Le Conte, Scott, and Tarr all assert the existence of these lakes without demur. Similar statements are naturally made by the standard European text-books, such as those by Geikie, de Lapparent, and Credner.

It is interesting to review the literature of this subject with the object of discovering how the theory of the lacustrine origin of the western Tertiaries was introduced, on what evidence it was based, and how thoroughly this evidence was discussed.

INTRODUCTION OF THE LAKE THEORY

The early volumes of Hayden's surveys afford such sentences as the following: "With the commencement of the Tertiary was ushered in the dawn of the great lake period of the West. The evidence seems to point to the conclusion that from the dawn of the Tertiary period, even up to the commencement of the present, there was a continuous series of fresh-water lakes all over the continent west of the Mississippi river. . . . The earliest of these great lakes marked the commencement of the Tertiary period, and seems to have covered a very large portion of the American continent west of the Mississippi, from the Arctic sea to the isthmus of Darien. . . . Every year, as the limits of my explorations are extended in

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* Tertiary History of the Grand Cañon District, p. 216.

† Ibid., p. 223.

‡ U. S. Geol. Survey Monograph, vol. xxvii, p. 525.

§ Fortieth Parallel Survey, vol. i, p. 489.

‖ U. S. Geol. Survey Monograph, vol. xxvii, p. 40.

any direction, I find evidence of what appear to be separate lake basins, covering greater or less areas." *

A later writer recapitulates his results as follows:

"Tertiary time in the region of the fortieth parallel is therefore represented by nine lakes—four Eocene lakes, which occupied the middle Cordilleras; . . . two Miocene lakes, one in the province of the plains, the other in western Oregon and western Nevada, and, lastly, the three Pliocene lakes." †

Quotations of this kind might be greatly multiplied, until the reader is convinced that during the last forty years it has become habitual to ascribe a lacustrine origin to the Tertiary formations here considered. In the face of these authoritative statements, it is disappointing to discover that no serious investigation of lake deposits has been published in any of the governmental reports concerning the western Tertiaries. From beginning almost to the end, the assertion has been made, without published critical discussion of the nature of the proof on which it rests. It is well known that an investigation of the kind here alluded to should consist of at least five steps, to enumerate no more. These are: careful observation and generalization of the observed facts, invention or application of an explanatory theory, deduction of the legitimate consequences of the theory, impartial comparison of the deduced consequences with the generalized facts, and, finally, judicial consideration of the value of the theory as measured by the degree of accordance between consequences and facts. Some of these steps have been taken in connection with the explanation of the western Tertiaries; others seem to have been neglected. The facts concerning the formations have been observed in abundance; an explanatory theory was introduced to account for the facts, and then, apparently without sufficient attention to the important steps of deduction and comparison, the correctness of the theory was authoritatively announced and widely accepted. The argument for the theory seems to have been about as follows: These Tertiary formations are stratified; hence they must have been deposited under water. They contain no marine fossils, but an abundance of fresh-water and land fossils; hence the water in which they were laid down could not have been that of the sea, but must have been that of large lakes, whose areas were at least as great as those of the formations now observable. Let us review the observed facts.

Composition of the Fresh-water Tertiary Formations

The fresh-water Tertiary formations in the Rocky Mountain region consist of a great variety of strata. Some of the strata are of fine texture, even bedding, and constant composition for a considerable thickness, as in the "paper shales" of the Green River basin of Wyoming; others are fine marls of great volume, as in the Eocene of the High plateaus of Utah; others are clays and very fine sands, as the White River beds of Nebraska; but, in strong contrast to these, there are frequently alternating layers of shales and sandstones, as in the central parts of the Vermilion Creek series, north of the Uintah mountains. The same formation contains extensive beds of conglomerates, of which the following passages give a vivid idea:

"West of Concrete plateau there is an enormous development of red sandstone

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* Geological Survey of the Territories, Second Annual Report, pp. 114, 115.

† Fortieth Parallel Survey, vol. i, p. 457.

and clays with prominent belts of conglomerate, the whole increasing in coarseness of sediment as it approaches the Uintah on the south and the Wahsatch on the west. Here is an area about sixty miles from north to south by fifty miles from east to west which is essentially a plateau of Vermilion Creek beds." *

Near the border of this early Eocene basin "conglomerates become more important, until directly north of the upper canyon of Weber river the mountain wall is composed of excessively coarse conglomerate between 3,000 and 4,000 feet thick. It is almost structureless, and lines of stratification can rarely be perceived. The blocks of which the conglomerate is chiefly formed range from the size of a pea to masses with a weight of several tons. . . . The rapidity with which these conglomerates grow finer in advancing from the shore along the Uintah is very conspicuous." †

The Arapahoe and Denver formations (closely associated with the Tertiary, if not actually belonging in this division of geological time), extending eastward from the base of the Front range in Colorado, consist chiefly of conglomerates and sandstones near the foothills and of finer sediments on the plains. In the foothills "the sandy parts of the bed develop in places to wedge-shaped masses, exhibiting in their relations to each other and to the conglomerates a very marked cross-bedding." ‡ On the plains a characteristic feature is "the irregular unconformable contact so frequently seen to exist between a conglomerate or grit layer above and a clay or shale layer below. . . . Often the unconformability is very marked. . . . The changes in conditions of sedimentation which gave rise to such stratigraphical relations of consecutive beds were, however, common in both Denver and Arapahoe epochs. Fine sediments were often disturbed and locally removed at the beginning of periods of rapid deposition of coarser materials." § Mention is made of "tree stumps in erect position with roots in mud layers and broken trunks in sand or gravel;" ‖ and it is recognized that the theory to account for these deposits must be conditioned "by the frequent cross-bedding observable both in sandstone and conglomerate, and by the plant remains and standing tree stumps that abound at certain horizons." ¶

Fossils contained in a geological formation are always regarded as highly significant of the conditions of deposition. The fossils of the western Tertiaries are chiefly land mammals and plants in great variety, to which are added the remains of birds of the air, reptiles of land or fresh water, fishes of fresh water, and molluscs of rivers, marshes, and lakes.

THEORIES OF LACUSTRINE AND FLUVIATILE DEPOSITS

If facts such as those above stated were today placed before a geologist for explanation he would undoubtedly begin his theorizing by excluding the sea as the place of deposition on account of the absence of marine fossils. He might then provisionally consider the possibility of lacustrine deposition, and here he could begin by reviewing what has been learned concerning the deposits now forming on

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* Fortieth Parallel Survey, vol. i, p. 372.

† Ibid., p. 369.

‡ U. S. Geol. Survey Monograph, vol. xxvii, p. 103.

§ Ibid., pp. 180, 181.

‖ Ibid., p. 168.

¶ Ibid., p. 33.

the floors of large and deep lakes. The testimony is universal that such deposits are of fine texture, and from this fact of observation it is reasonably inferred that deep lake deposits must be of even stratification and of persistently uniform composition, as long as the lake remains large and deep. The marginal deposits may be of fine or coarse texture, according to the nature of the shores and to the size and contents of the rivers that drain them. In time these coarser deposits will invade the lake basin and overlap the finer deposits of the shoaling bottom. If a large shallow lake is next considered, it may be imagined that the winds could produce waves and currents strong enough to produce cross-bedding and other irregular structures in sandy and pebbly layers, and hence that such layers might alternate with others of finer texture; but the shallower the lake, the more rapid the invasion of its shores by marginal deposits, the upper part of which will be of subaerial, not lacustrine, deposition; the shallower the lake, the more likely its extinction by evaporation or by erosion of the outlet. When the lake is destroyed, deposition might continue under the action of aggrading streams and rivers, and thus the way is led to the consideration of fluviatile plains, many examples of which, much larger in area than any existing shallow lakes, are now open to observation. The emphasis usually given to the destructive activities of rivers should not prevent the due examination of their constructive work, so abundantly exhibited on great river-made plains. Observation on such plains shows the capacity of rivers to form deposits of variable composition, texture and structure near the border of the plains, and of fine texture and comparatively even structure further forward along the course of the streams. Thus the essential characteristics of lacustrine and fluviatile deposits may be generalized in form appropriate for theoretical discussion.

Choice of the Successful Theory

The consequences of the theories of lacustrine and fluviatile deposition should be confronted with the assembled and generalized facts that have been determined by observation of the western Tertiaries, in order to determine how the latter are best explained. It will then perhaps be possible to decide whether the Tertiary epochs of Rocky Mountain history should be pictured with broad and level sheets of blue water stretching between distant ranges, whether extensive gently sloping plains of gravel, sand, and clay should occupy most of the intermont basins, or whether some combination of these unlike conditions best meets the conditions of nature.

Without desiring to announce any special proportion in which the rival explanations should be associated, and without attempting to conceal my individual leaning toward a fluviatile or other subaerial origin for many of the formations that are ordinarily described as lacustrine, it is desirable to make mention of certain statements in various reports which suggest that their writers had certain qualifications of the purely lacustrine theory in mind. It is true that the chief emphasis is given to "large lakes," and that the sediments are repeatedly said to be lake-bottom formations, but the lake waters are sometimes described as shallow, and alternations of shallow water and low land are given brief mention in one report, which, however, elsewhere refers to the seat of deposition as "the sea" or "the lake." The lake waters are described by some as having sometimes had movement enough to distribute sands and pebbles. The movement is once characterized as "turbulent." It is quite possible that certain authors intended to include subaerial marginal deposits under the general heading of lacustrine deposits, and that they tacitly allowed a considerable volume to deposits thus accumulated, although there is repeated implication that even the coarser sediments were laid down on the lake side, not on the land side of the "shorelines," below water-level and not above. River action may have been taken for granted, as so naturally associated with lake deposits that no mention of it was thought to be necessary. However all this may be in the minds of the writers, there is no question that the readers of the reports of the western surveys will be led by the repeated mention of lakes and by the almost universal silence about rivers to regard the whole body of the western Tertiaries, coarse and fine, as lacustrine, and a reference to the text-books above mentioned will substantiate this statement. Whatever qualifications of the lacustrine theory may have been in the minds of the older geologists, who are familiar with the facts by direct observation, it is not likely that any qualifications of the theory will enter the minds of the rising generation of geologists when they first meet the current descriptions of the wonderful lake deposits of the West in text-books or in governmental reports, and it is particularly in this connection that it seems advisable to promote discussion on the subject here presented.

More important than the tacit qualifications of the lacustrine theory that may have a place in the minds of some geologists, the expressed opinions of other geologists on this subject deserve mention. In the first place, it should be pointed out that the investigations of the Quaternary lakes of the West seem to have been conducted on somewhat different principles from those which obtained in the study of the Tertiary lakes. In the Bonneville and Lahontan basins intercalated deposits of gravels and sands are taken as indicating a non-lacustrine interval between the lacustrine epochs in which underlying and overlying marls and clays were laid down. Furthermore, the Pliocene sediments of the plains in Colorado and Kansas have been explicitly described as fluviatile by two observers, Gilbert and Haworth, and the eolian origin of the White River clays of Nebraska has recently been discussed by Matthew. In Europe Penck has called attention to the essentially fluviatile origin of such basin deposits as occupy the plains of Hungary and of the middle Rhine, and it is from this geologist that I have learned the term continental as a general name for lacustrine, fluviatile, and eolian deposits, in contrast to marine deposits; and both Penck and Goodchild have attributed the heavy and coarse Torridon sandstones and conglomerates of northwest Scotland to accumulations on an arid land surface. In view of all these considerations, it does not seem too much to say that the habitual explanation of our western fresh-water Tertiary formations as lake deposits stands in need of thorough and critical revision.

Discussion

F. S. Emmons said

That Professor Davis' remarks seemed to apply specially to the Fortieth Parallel work, in which he took part, since theirs was the first to attempt to differentiate and roughly outline the Tertiary basins of the Rocky Mountain region. He seemed to imply that these geologists had assumed that any non-marine Tertiary beds observed were necessarily deposited in a Tertiary lake without stopping to consider the possibility of any other origin. Their geological work was confessedly not a survey, but a reconnaissance, and as such their results would necessarily be subject to modification by more detailed work, especially when done in the light of modern advances in geological and geographical knowledge. They had hoped that long before this these Tertiary deposits would have been made the object of special geological studies, for there were many facts with regard to them that could not be satisfactorily determined in these hasty and, as regards their actual area, very imperfect observations; yet I can hardly feel willing to admit that such polemic statements as those made by Professor Davis, where not based on any new observations, cast any doubt on the correctness of their conclusions with regard to these deposits. With the exception of those on the Great plains east of the Rocky mountains, the Tertiary lake deposits there noted occur in basins still enclosed within mountain ranges where no considerable fluviatile action is conceivable. In all, the character of bedding and nature of successive beds is such as to necessitate their having been deposited in still waters.

In the case of the Vermilion creek (Wahsatch) beds cited by Professor Davis, the great thickness of conglomerates mentioned is found in the southwest corner of the Green River basin, in the right angle formed by the lofty Wahsatch and Uintah ranges, and was evidently washed down rapidly from the then even steeper slopes of these ranges and spread out along the shoreline of the lake. What its exact relations to the shore were, and whether it represented the shoreline phase only of the lower or Vermilion Creek series, or of the overlying Green River and Bridger series as well, we had not the time to determine. Toward the center of the basin the beds of all the series become so thinly, uniformly, and evenly bedded as to preclude the possibility of fluviatile deposition, especially as they were formed in what is now, as well as could be determined, an enclosed basin without outlet.

Something in the nature of Professor Davis' fluviatile origin was suggested by me for the latest phase of deposition in this region for what I called the Wyoming conglomerate (Bishop Mountain conglomerate of Powell), which was spread out over the flanks of the Uintah range in a sort of sheet-flood deposit without stratification, but which left no fine grained representatives toward the middle of the basin. A similar origin to this is also conceivable for some of the coarser beds on the eastern flanks of the Rocky mountains, and a fluvio-lacustrine origin was suggested by me as one of the possibilities of the loess of the Denver basin. As for the Denver and Arrapahoe beds, I will resign the floor to Mr Cross, who is more intimately acquainted with them by personal observation.

Mr Whitman Cross said in substance the following:

Since the abstract of Professor Davis' paper, which we have heard, deals only with general principles, and did not contain special references to the formations whose origin he questions, I can not directly discuss the points he may raise as to the origin of the Arapahoe and Denver beds. In general, however, the hypothesis of a fluviatile origin for them must explain many facts besides those evident from the texture and composition of the strata. Since these formations were first discovered numerous other formations of the same lithologic character, the same details of texture, and in several cases shown to be of the same age by fossil remains, have been found in various parts of Colorado, namely, in South park, some 50 miles southwest of Denver; in Middle and North parks, to the northwest of Denver; at Canyon City; on the Animas river south of the San Juan mountains, and on the western flanks of the Elk mountains, in the western part of the State. The Denver and Arapahoe beds together are known to have a thickness of more than 2,000 feet; the Middle Park beds are more than 6,000 feet in thickness, according to the reports of A. R. Marvine; the South Park beds are also of considerable thickness; the Animas River beds exceed 1,000 feet in thickness, and the Ruby beds, west of the Elk mountains, reach a thickness of 2,000 feet. If one of these formations be supposed to be of fluviatile origin from anything in the texture or composition of the strata, then all must be placed in the same category for the same reason.

It is further certain from a field examination of these formations that they had very much greater lateral extent at the time of deposition than they now possess, as well as a greater thickness in some cases. This seems to me a very important factor in the problem, making it absolutely essential to give some plausible grounds for the assumption that rivers once existed capable of the accumulation of such enormous masses of finely stratified matter at so many points in the mountains of Colorado. It is also to be taken into account that the Livingston formation of Montana, identical in lithologic character and known to be of the same age as the Denver beds, has a thickness of over 7,000 feet, according to Mr W. H. Weed.

The present relation of the Great plains to the Rocky Mountain front near Denver may suggest to a physiographer that formations of fluviatile origin are to be looked for in the vicinity of the mountains, either in the valleys of the present streams or as remnants of older deposits, but it can not be assumed that mountain and plain occupied this relation to each other in the period of the Denver formation. The Denver beds are upturned in vertical position at the base of the foothills, and great orographic movements have taken place in several parts of Colorado since the deposition of the equivalent formations.

These formations have been described as lacustrine by those who have studied them in the field, and it appears to me that the burden of proof rests on Professor Davis in advocating a fluviatile origin for them.

Remarks in discussion were also made by W. H. Weed, I. C. Russell, and the President. In closing the discussion Professor Davis spoke as follows:

For evidence of the habitual reference of the fresh-water Tertiaries to a lacustrine origin I refer again to such a quotation as that from Dutton given in my paper. As to the occurrence of coarse and variable strata among deposits that have been classed as lacustrine, the most striking examples that I have found are contained in the account of the Vermilion Creek beds in the Report of the Fortieth Parallel Survey, and in the description of the Arapahoe and Denver formations in the Monograph on the Denver Basin, United States Geological Survey. The foregoing discussion of the origin of these deposits seems to me appropriate, in spite of my not having studied the localities where the formations occur. It is not proposed to question the facts of observation, which are accepted as reported, but to *discuss the discussion* by which the reported facts are interpreted. Every geologist must carry on his own discussion of the methods by which others reach their theoretical results, unless he merely accepts the results along with the facts. It is the more necessary that each student of our western geology should discuss for himself the lacustrine origin of the fresh-water Tertiary deposits of the Rocky

Mountain region, because, with very few exceptions, no such discussion has been published by the observers who have reported the facts and theories. What the conclusion of the discussion will be remains to be seen, but the discussion seems to me extremely desirable. In the mean time I do not desire to assert either a lacustrine or a fluviatile origin for these formations.

The four following papers were read by title:

ON THE AGE AND DISTRIBUTION OF THE SEDIMENTARY ROCKS OF PATAGONIA

BY J. B. HATCHER

CRETACEOUS INVERTEBRATES FROM PATAGONIA COLLECTED BY J. B. HATCHER

BY T. W. STANTON

ENRICHMENT OF MINERAL VEINS BY LATER METALLIC SULPHIDES

BY WALTER HARVEY WEED

This paper is printed as pages 179 to 206 of this volume.

VEIN FORMATION AT BOULDER HOT SPRINGS, MONTANA

BY WALTER HARVEY WEED

The following paper was read by the author:

HERONITE AND ITS RELATED ROCKS

BY A. P. COLEMAN

The next paper was entitled:

IGNEOUS COMPLEX OF MAGNET COVE, ARKANSAS

BY HENRY S. WASHINGTON

Remarks were made by J. P. Iddings, L. V. Pirsson, W. H. Weed, and the author. The paper is printed as pages 389 to 416 of this volume.

The last paper read was the following:

FURTHER STUDIES ON THE HISTORY OF THE CINCINNATI ANTICLINE

BY AUG. F. FOERSTE

In discussing the paper W. M. Davis said:

The section given by Doctor Foerste shows that the strata of the Cincinnati arch were denuded to a lowland enclosed by a monoclinal ridge of small relief before the unconformable deposition of the Devonian beds. The thickness of the overlying strata is less on the monoclinal ridge than on the lowland within and without. If, as is probable, the arch was denuded by subaerial forces, it is to be expected that outflowing consequent streams must have here and there cut notches in the ridge; and if these notches were now open to observation, the covering strata should be found as thick there as on the inner and outer lowland. This suggests that search should be made for such local thickening of the covering strata; if found, it could be accepted as decisive evidence of subaerial denudation of the arch.

The paper was also discussed by M. R. Campbell and C. W. Hayes.

The remaining papers of the program were read by title, as follows:

GEOLOGICAL STRUCTURE OF COFFEYVILLE (KANSAS) GAS FIELD

BY G. PERRY GRIMSLEY

SURFACE TEMPERATURE OF THE EARTH

BY ALFRED C. LANE

GLACIATION OF MOUNT KTAADN, MAINE

BY RALPH S. TARR

This paper is printed as pages 433 to 448 of this volume.

POST-GLACIAL TIME IN HURON COUNTY, MICHIGAN

BY ALFRED C. LANE

This paper is printed in Reports of the Geological Survey of Michigan, 1900, volume vii, part ii, chapter 4.

*KEEWATIN OF EASTERN CENTRAL MINNESOTA**

BY C. W. HALL

*KEWEENAWAN OF EASTERN CENTRAL MINNESOTA**

BY C. W. HALL

GEOLOGY OF QUEBEC CITY AND ITS ENVIRONS

BY HENRY M. AMI

GAS WELL SECTIONS IN UPPER MOHAWK VALLEY AND CENTRAL NEW YORK

BY CHARLES S. PROSSER

This paper is printed in the *American Geologist*, March, 1900, volume xxv, pages 131–162.

VERTEBRATE FOOTPRINTS ON CARBONIFEROUS SHALES OF PLAINVILLE, MASSACHUSETTS

BY J. B. WOODWORTH

This paper is printed as pages 449 to 454 of this volume.

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* These papers will probably be published in volume 12. They could not be completed in time for this volume.

RECONNAISSANCE IN SOUTHEASTERN ARIZONA

BY E. T. DUMBLE

GEOLOGY OF THE WICHITA MOUNTAINS

BY H. FOSTER BAIN

This paper is printed as pages 127 to 144 of this volume.

VOLCANICS OF NEPONSET VALLEY, MASSACHUSETTS

BY F. BASCOM

This paper is printed as pages 115–126 of this volume.

CAMBRO-SILURIAN LIMONITE ORES OF PENNSYLVANIA

BY T. C. HOPKINS

This paper is printed as pages 475–502 of this volume.

CONTACT METAMORPHISM OF A BASIC IGNEOUS ROCK

BY U. S. GRANT

This paper is printed as pages 503–510 of this volume.

THE COMPOSITE ROCK DIAGRAM

BY W. H. HOBBS

The substance of this paper is printed in the Journal of Geology, volume viii.

RELATIONS BETWEEN THE OZARK UPLIFT AND ORE DEPOSITS

BY ERASMUS HAWORTH

This paper is printed as pages 231 to 240 of this volume.

The scientific work of the meeting was declared completed.

On motion of W. M. Davis, a resolution of thanks was voted to Fellows of the Local Committee for their careful provision for the success of the meeting, and to the Washington Academy of Sciences for the reception of Friday evening.

The Society then adjourned.

Register of the Washington Meeting, 1899

The following Fellows were in attendance at the meeting:

Cleveland Abbe, Jr.
T. H. Aldrich.
A. P. Brigham.
M. R. Campbell.
W. B. Clark.
J. M. Clarke.
A. P. Coleman.
Whitman Cross.
H. P. Cushing.
N. H. Darton.
W. M. Davis.
D. T. Day.
R. E. Dodge.
B. K. Emerson.
S. F. Emmons
H. L. Fairchild.
G. K. Gilbert.
A. W. Grabau.
G. P. Grimsley.
F. P. Gulliver.
Arnold Hague.
J. B. Hatcher.
C. W. Hayes.
C. H. Hitchcock.
W. H. Hobbs
J. A. Holmes.
E. O. Hovey.
E. E. Howell.
J. P. Iddings.
Arthur Keith.
J. F. Kemp.
C. R. Keyes.
W. C. Knight.
F. H. Knowlton.
H. B. Kummel.
Waldemar Lindgren.
W J McGee.
G. P. Merrill.
F. H. Newell.
W. H. Niles.
R. A. F. Penrose.
L. V. Pirsson.
J. H. Pratt.
F. L. Ransome.
H. F. Reid.
W. N. Rice.
Heinrich Ries.
I. C. Russell.
R. D. Salisbury.
Charles Schuchert.
G. B. Shattuck.
G. O. Smith.
J. C. Smock.
A. C. Spencer.
J. W. Spencer.
T. W. Stanton.
J. J. Stevenson.
J. A. Taff.
W. G. Tight.
H. W. Turner.

T. W. Vaughan.
C. D. Walcott.
H. S. Washington.
W. H. Weed.
David White.
I. C. White.
H. S. Williams.
Bailey Willis.
J. B. Woodworth.
W. S. Yeates.

Fellows-elect

A. S. Eakle.
A. F. Foerste.

Total attendance, 72.

SESSION OF THE CORDILLERAN SECTION, FRIDAY, DECEMBER 29

The announcement of the meeting, preceding the preliminary list of papers, was as follows:

> A year ago about a dozen west coast geologists met at Berkeley and organized the Cordilleran Geological Club. The organization was at once recognized as temporary, and the project of organizing permanently as a section of the Geological Society of America formed a leading topic of discussion at the meeting. The following spring a number of Fellows of the Society resident in California memorialized the Council of the Society,* setting forth their inability to be present at the meetings of the Society owing to the great distance at which they reside from the usual places of meeting, and praying for legislation on the part of the Society which would enable them to meet as a geographically distinct section of the Society. Since the memorial was forwarded to the Secretary there has been no meeting of the Council, but the Secretary states that such an organization would be within the constitution, and advises that the organization be proceeded with. Prominent Fellows of the Society in the East have been consulted, and have also cordially commended the project as consistent with and serving the main purposes of the Society.
>
> Under these circumstances, the undersigned, with the approval of several Fellows of the Society with whom he has consulted, has ventured to call a meeting of Fellows resident in the Cordilleran portion of the country, to be held on December 29 and 30, 1899, in the rooms of the Academy of Sciences, San Francisco, California.
>
> The purpose of the meeting will be to effect such organization, under the constitution of the Society, as the circumstance of separate meetings may seem to demand, and to participate in the discussion of geological questions.
>
> ANDREW C. LAWSON.
>
> BERKELEY, CALIFORNIA, *December 3, 1899.*

The meeting was called to order at 11 o'clock a m, in the council-room of the Academy of Sciences.

The Section was organized by electing Joseph Le Conte chairman and Andrew C. Lawson secretary.

An executive committee, consisting of the Chairman and Secretary and J. E. Talmage, to attend to the affairs of the Section, was appointed.

The Executive Committee was authorized to pass upon accounts of expenditures and to arrange the time and place of the next meeting.

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*See page 587 of this volume.

SESSION OF THE CORDILLERAN SECTION, SATURDAY, DECEMBER 30

The following paper was read by J. C. Merriam, in the absence of the author:

*GOAT-ANTELOPE FROM THE CAVE FAUNA OF PIKES PEAK REGION**

BY F. W. CRAGIN

The two principal Manitou caves, the cave of the Winds and the Grand caverns, are well known to all transcontinental tourists who have visited Manitou. They are in the lowest Silurian formation, which, in the Pikes Peak Folio of the Geologic Atlas of the United States, Mr Whitman Cross has named the "Manitou limestone." Other and smaller caves are frequent in the same formation.

From the cave of the Winds and the Grand caverns considerable cave-earth has been taken in the process of restoring some of the galleries and chambers to original or convenient dimensions, but no evidences of an extinct fauna have thus been brought to light.

In having the cave-earth removed from a cave in the Manitou limestone of his Glen Eyrie estate a few years since, General William J. Palmer, with his usual foresight, saved the organic remains, consisting of a number of bones thrown out with the earth by the workman, and these he very kindly submitted to the writer for determination.

Two of the specimens were at once recognized as proximal phalanges of a slender-limbed type of horse occurring elsewhere in the interior west, associated with the remains of elephants, ground sloths, llamas of cameline, as well as of smaller, size, large carnivores, and land tortoises of late Pliocene or Quaternary age, and thus indicating for the cave at least a corresponding antiquity.

The other remains found in the cave at Glen Eyrie were identified last summer, when the writer was first able to compare them with extensive series of skeletons in the United States National Museum. The smaller bones, a jaw and two femurs, were soon found to belong to a species of woodchuck, different from the common one of eastern North America, and not improbably so from the yellow-bellied woodchuck which is the present species of the central Rocky mountains. The larger bones pertained to the right forelimb of a young ruminant, or two-toed ungulate, which some ancient beast of prey had doubtless dragged into the cave as a choice morsel to feed on at leisure. They were humerus and cannon-bone, in which part of the epiphyses were missing, not yet having united with the shaft. It was at first thought that they might have pertained to a Rocky Mountain sheep, or bighorn. From the skeleton of this, however, they widely differed, as they also did from that of the mountain goat, mazama. From all other recent North American two-toed ungulates the departure was still wider. Reference was, however, made to Asiatic forms, and it was soon found that the bones in question closely agreed with those of the capricorn or goat-antelope genus, *Nemorhædus*, represented today by several species living in the Himalayas and other mountains of Asia, Japan, and Formosa. Of this genus there are two sections. One includes clumsier-

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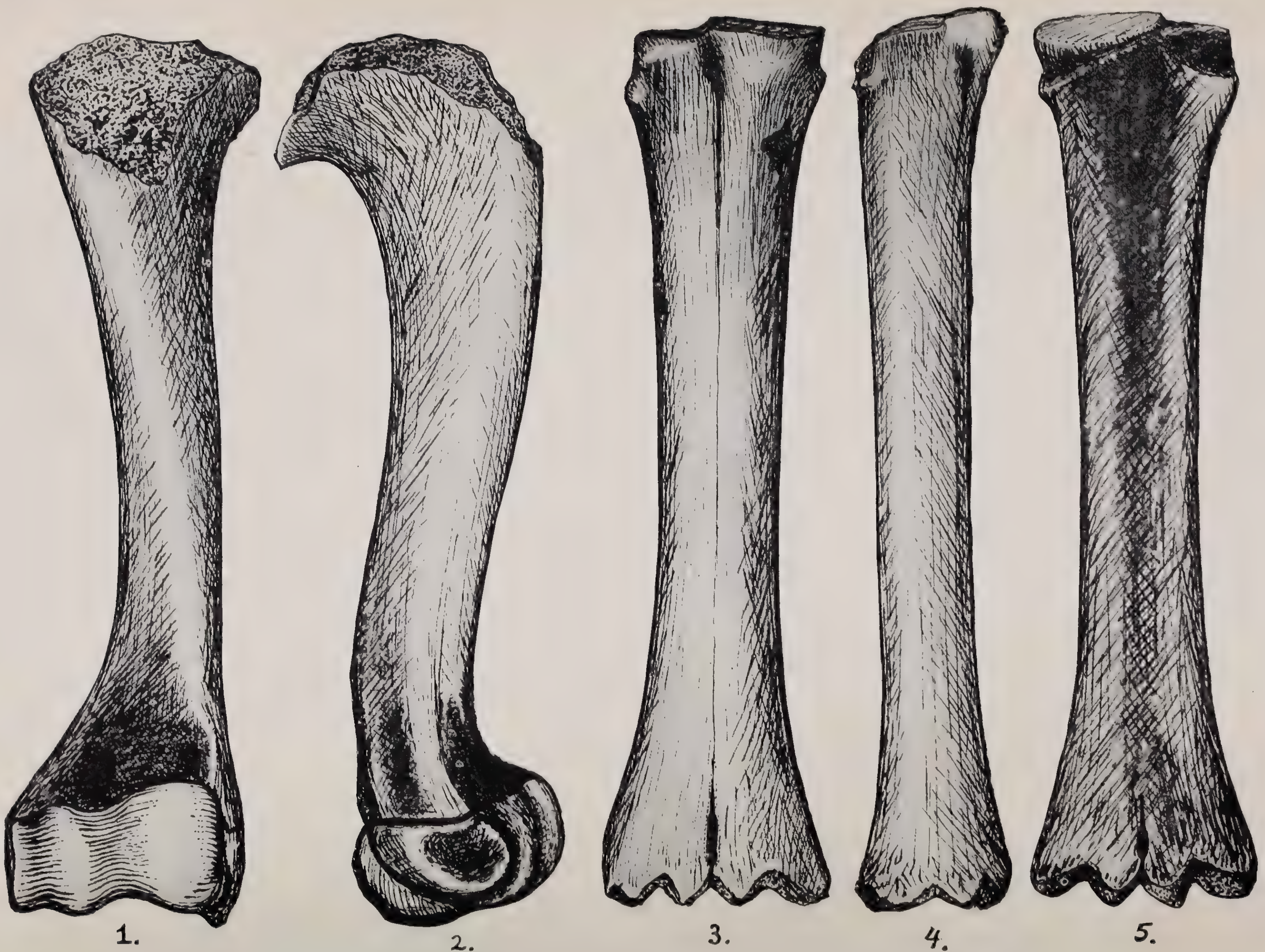
*Owing to the unfortunate loss of the specimens it became necessary to use the rough drawings made from them to illustrate this paper, instead of reproducing photographs as originally intended.—ED.



RIGHT HUMERUS AND RIGHT METACARPUS OF NEMORHŒDUS PALMERI CRAGIN

1 and 2, humerus; 3, 4, and 5, metacarpus

built animals, which, however, resemble the deer in having a tear-pit in the face and which are solitary in habit. These are the serows, of the subgenus *Capricornis.* The other, of the section or subgenus *Kemas,* includes more graceful forms, the gorals, which lack tear-pits and go in small parties. It is impossible, in the absence of a skull from the Glen Eyrie Cave material, to be quite sure whether the particular species of *Nemorhœdus* that inhabited the Pikes Peak region, and which, in recognition of General Palmer's liberal patronage of science and education, I shall call *Nemorhœdus palmeri,* was a serow or a goral. Of the serows, the osteological collections of the National Museum included a skull, but no skeleton; but the agreement of the two limb bones with the corresponding ones of the species of goral in the Museum (*Nemorhœdus crispus,* or *Kemas crispus,* of Japan) is such that the differences can hardly be considered of more than specific value, and it seems probable that our Rocky Mountain goat-antelope was a goral. A glance, therefore, at the species of goral that inhabits an interior mountain region of Asia corresponding with ours of North America may be of sufficient interest to take in this connection. The following account of the goral of the Himalaya is collated from Jerdon's "Mammals of India" and Lydekker's "Chapters on Hoofed Animals":

The animal is very caprine in appearance, the back somewhat arched, the limbs stout and moderately long. It is well adapted for both climbing and jumping. It stands some 27 to 30 inches high at the shoulder, the head and body measuring 50, the tail 4, and the horns 8 inches in length. The horns, which are present in both sexes, and only a little larger in the male than in the female, incline backward and slightly inward, and are a little recurved. They are shorter than the skull, black in color, round in cross-section, and ornamented with 20 to 25 encircling raised folds. The fur is somewhat rough, of two kinds of hair, and there is a short, semi-erect mane in the male. The color is brown, with a more or less decided gray or ruddy tinge, a little lighter beneath. The throat is white. A dark line runs down the back from crown to tail, and the front surface of the legs are also marked with dark streaks. Though found considerably higher and lower, ranging from 3,000 to 8,000, the Himalayan gorals are commonest at elevations of 5,000 to 6,000 feet above sealevel. They inhabit rugged grassy hills and rocky ground in the midst of forests, and are usually found in small family parties of three to eight. If one goral is seen, you may be pretty sure that others are not far off. They rarely or never forsake their own feeding grounds. In cloudy weather they feed at all hours of the day; in fair weather, only morning and evening. When one is alarmed, it gives a short hissing sound, which is answered by all within hearing.

The Glen Eyrie cave bones of the *Nemorhœdus,* though considerably less discolored and mineralized than those of the horse, are well preserved and appear intermediate in this respect between the latter and those of the woodchuck; but it is, of course, impossible to draw from this any certain inference as to the relative geological age of the specimens, since the petrifactive conditions may have varied in different parts of the cave-earth; yet, so far as the evidence goes, it tends to indicate a greater antiquity for the horse bones.

If the range of the Pikes Peak capricorn corresponded nearly with that of the Himalayan, and the cave of the capricorn-eating carnivore was conveniently located within the zone of the greatest abundance of the quarry—5,000 to 6,000 feet above sealevel—the Rocky Mountain plateau must have stood something like one or two thousand feet lower in its capricorn epoch than today, as the present elevation of the cave approaches 7,000 feet; and as the two conditions above predicated are those most likely to have prevailed, it seems quite probable that *Nemorhœdus*, as an element of the North American fauna, belonged to the Champlain phase of the Glacial epoch.

The finding of goat-antelopes as members of an extinct fauna of the Rocky mountains, while it was quite unexpected, is no more remarkable than that elephants, which, not only by present habitat but also by the very place of their origin from the mastodon stock, are Asiatic types, abounded in Pleistocene times throughout all North America, to which the Asiatic fauna doubtless had measurable access by way of lands now interrupted in the vicinity of Bering strait. The Asiatic mammoth, *Elephas primigenius* var. *primigenius*, occurs in trans-sierran America, and elephant remains of an extinct species, related to the mammoth and to the modern Asiatic rather than to the African elephant, are common on the Great plains and have been found in the Rocky mountains as high, at least, as the bogs of Grassy gulch in the Cripple Creek mining district.

The cave fauna of Glen Eyrie was first publicly described in a popular lecture delivered by the writer before the Colorado College Scientific Society on the 27th of October last, and which was printed in the Colorado Springs Gazette of November 12.

The writer wishes to acknowledge his indebtedness in this connection to the departments of the National Museum in charge of Messrs F. A. Lucas and F. W. True for facilities of study granted, and particularly to Mr Marcus W. Lyon, Jr., who personally assisted him in comparing the Glen Eyrie cave specimens of *Nemorhœdus* and *Arctomys* with recent osteological material.

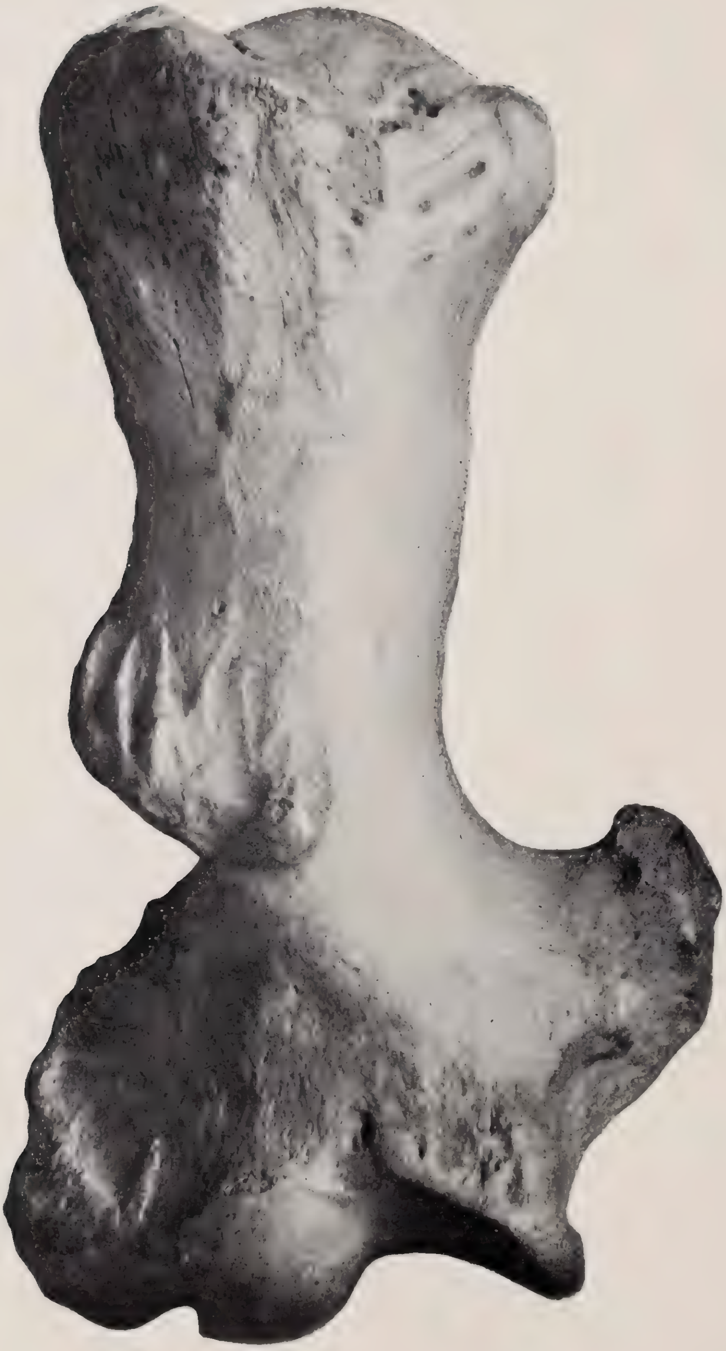
The seven following papers were read by the authors:

GROUND SLOTHS IN THE CALIFORNIA QUATERNARY

BY JOHN C. MERRIAM

Among the vertebrate fossils which have been brought to light in middle California within the past year there are two specimens which are of more than ordinary interest, as they indicate the existence of that peculiar group of mammals known as ground sloths in this region, within comparatively recent times. The first of these specimens to become known was a large humerus, received by the writer for determination from Mr A. Huff, who had found it near Hamlet station, on the east side of Tomales bay. In August last the writer visited Hamlet in order to determine if possible the exact occurrence of the humerus, but was not able to do so, owing to the absence of Mr Huff. Two months later Mr F. C. Calkins visited the locality at the writer's request and examined the spot from which the humerus was taken. To Mr Calkins I am indebted for the exact data relating to its occurrence.

The place pointed out to Mr Calkins as that from which the humerus was obtained is in a small run about three-quarters of a mile southeast of Hamlet and about 100 feet above the level of the bay. The stream in the run has cut down quite sharply for about 12 feet into a loose, sandy clay at the spot where the specimen was obtained. Above this point it flows through or over deposits similar to those just mentioned, and over rocks of the Franciscan series, so that the specimen must be derived from one or the other of these formations. As the Franciscan rocks are of middle Mesozoic age and have suffered much disturbance, the



RIGHT HUMERUS OF MOROTHERIUM GIGAS MARSH

(A little less than one-fourth natural size) only possible source of such a specimen as that which we have under consideration is the more recent deposit.

Incoherent, yellowish, sandy clays, similar to those just mentioned, form the most prominent feature of the geology along the east side of Tomales bay between Point Reyes station and Hamlet. In many places they form prominent seacliffs up to 40 feet in height. They are everywhere unsolidified and frequently show horizontal stratification. Mr Calkins considers the beds in the stream cutting in which the humerus was found as an extension of this deposit up the slope of the hill. Judging from their incoherent nature and horizontal stratification, these beds are certainly much younger than the latest Pliocene in the region. Excepting the humerus, the only fossil obtained from them is a badly worn elephas tooth, which was picked up on the shore of Tomales bay near Point Reyes. This formation resembles the deposits along the shores of San Pablo and Suisun bays, in which a Quaternary fauna, both molluscan and mammalian, has been obtained by the writer. In this connection the preservation of the specimen is a noteworthy character, as the bone is absolutely intact and the original material unchanged. One might almost suppose it a product of the last half century.

Two edentate humeri, much resembling the specimen under consideration, have been described from western North America. The first specimen was discovered on the Willamette river, Oregon, in 1839, by Mr Ewing Young. In 1842 it was described and figured by H. C. Perkins.* The humerus and a large gravigrade tooth, associated with elephas and bos or bison remains, were found about 12 feet below the surface, presumably in a Quaternary deposit. This specimen was provisionally named *Orycterotherium oregonensis*, but was afterward referred to *Mylodon* by Sir Richard Owen.

The other specimen, together with a femur, was obtained by Marsh from Alameda county, California (locality unknown), and was described by him as the type of a new genus, *Morotherium*, species *gigas*. Marsh considered *Morotherium* most nearly related to *Megalonyx* and *Mylodon*, being distinguished from the former by the absence of a supra-condylar foramen in the humerus, and from the latter by the absence of a depression for the round ligament in the head of the femur.

Unfortunately in the type specimen of *Morotherium gigas* the only portion of the humerus preserved is the distal end, minus the outer and inner condyles, so that it is not possible to make a satisfactory comparison. To as much of it as is preserved, the Tomales Bay specimen shows a strong resemblance. With the Willamette River humerus, of which good outline drawings were given by Perkins, our specimen agrees perfectly, excepting in one particular. In Perkins' drawings the deltoid ridge shows a deep narrow notch near the lower end, which is not present in the Tomales Bay specimen. In his article Perkins states that there are *remains* of a large protuberance on the outside of the humerus, a little more than half way down the body of the bone, so that the notch in the deltoid ridge is possibly an irregularity in the weathered or broken bone. In the figures of the humerus of Mylodon which the writer has seen no such notch appears. The two specimens are of nearly the same dimensions throughout. The principal difference is in the length, the Willamette specimen measuring about 20, the other 18½ inches long. The humerus of *Morotherium gigas* is about the same size as the other two specimens.

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* Amer. Jour. Sci., vol. 42, p. 137.

It is not improbable that the Willamette mylodon, *Morotherium gigas*, and the Tomales Bay form are all of the same genus, possibly of the same species. Possibly they are all *Mylodon*, but since the humerus is not well preserved in *Morotherium*, and the femur, on which that genus was based, is absent in the other two specimens, it is not possible at the present time to determine their relationships satisfactorily.

Though it is not fully apparent to the writer that the genus *Morotherium*, as defined by Marsh, stands on a perfectly firm foundation, that name will be applied to the Tomales Bay specimen until further evidence can be obtained.

The second acquisition consists of fragments of humeri from near Martinez, Contra Costa country. They include a distal end, possibly also the proximal end, of a right humerus, presented to the University of California by Judge Jones, of Martinez. These fragments were obtained by him some years ago from a loose, horizontally stratified deposit along the shore of Suisun bay, east of the town. Associated with them were bones and teeth of elephas and of a large species of Equus. The fragment representing the distal end of the humerus shows the articular surfaces, the outer condyle, and the supinator ridge perfectly, but the inner condyle is missing. It very closely resembles the specimen from Tomales bay, but is possibly from a somewhat larger animal, in which the lower end of the deltoid ridge was a little less prominent than in that form.

Several miles west of Martinez, along the shore of San Pablo bay, there are numerous occurrences of a deposit similar to that east of the town. In these beds there have been found remains of elephas and bison (?), along with a marine fauna, consisting of recent species, so that there can be no doubt as to the Quaternary age of the deposit. The beds at Tomales bay evidently belong to the same epoch as those of San Pablo and Suisun bays. It is probable that the other mylodon-like remains from this coast, including the footprints at Carson, Nevada, also belong to the Quaternary.

CLASSIFICATION OF THE JOHN DAY BEDS

BY JOHN C. MERRIAM

An abstract is published in Science, February 9, 1900, volume xi, page 219.

NOTES CONCERNING EROSION FORMS AND EXPOSURES IN THE DESERTS OF SOUTH CENTRAL UTAH

BY J. E. TALMAGE

A brief abstract is published in Science, February 9, 1900, volume xi, page 220.

PECULIAR MARKINGS ON SANDSTONES FROM GLEN CANYON, ARIZONA

BY J. E. TALMAGE

A brief abstract is published in Science, February 9, 1900, volume xi, page 220.

CONGLOMERATE "PUDDINGS" FROM PARIA RIVER, UTAH

BY J. E. TALMAGE

A brief abstract is published in Science, February 9, 1900, volume xi, page 220.

AN EARLY GEOLOGICAL EXCURSION

BY JOSEPH LE CONTE

A brief abstract is published in Science, February 9, 1900, volume xi, page 221.

THE SANDSTONE REEFS OF BRAZIL

BY JOHN C. BRANNER

The ninth paper was read by A. C. Lawson, in the absence of the author:

A TOPOGRAPHIC STUDY OF THE ISLANDS OF SOUTHERN CALIFORNIA

BY W. S. TANGIER SMITH (INTRODUCED BY A. C. LAWSON)

A brief abstract is published in Science, February 9, 1900, volume xi, page 221.

The tenth paper was read by title:

THE GEOLOGICAL SIGNIFICANCE OF SOIL STUDY

BY E. W. HILGARD

A brief abstract is published in Science, February 9, 1900, volume xi, page 221.

The eleventh paper was read by the author:

THE PENEPLAIN QUESTION ON THE PACIFIC COAST

BY H. W. FAIRBANKS

The next two papers, in the absence of the authors, were read by A. C. Lawson:

THOMSONITE, MESOLITE, AND CHABAZITE FROM GOLDEN, COLORADO

BY HORACE B. PATTON

The paper is printed as pages 461 to 474 of this volume.

THE AMERICAN DEVONIAN PLACODERMS

BY E. W. CLAYPOLE

The fourteenth paper was read by the author:

THE BERKELEY HILLS—A DETAIL OF COAST RANGE GEOLOGY

BY ANDREW C. LAWSON

The fifteenth and last paper was read by A. C. Lawson, in absence of the author:

SOME COAST MIGRATIONS, SANTA LUCIA RANGE, CALIFORNIA

BY BAILEY WILLIS

The paper is printed as pages 417 to 432 of this volume.

Register of San Francisco Meeting of Cordilleran Section

J. C. Branner.
H. W. Fairbanks.
E. W. Hilgard.
A. C. Lawson.
Joseph Le Conte.
J. C. Merriam.
J. E. Talmage.

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FELLOWS, JUNE, 1900

*Indicates Original Fellow (see article III of Constitution)

Cleveland Abbe, Jr., Ph. D., Rock Hill, S. C.; Professor in Winthrop Normal College of South Carolina. August, 1899.

Frank Dawson Adams, Ph. D., Montreal Canada; Professor of Geology in McGill University. December, 1889.

José Guadalupe Aguilera, Esquela N. de Ingeneiros, City of Mexico, Mexico; Director del Instituto Geologico de Mexico. August, 1896.

Truman H. Aldrich, M. E., Birmingham, Ala. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

Philip Argall, 821 Equitable Building, Denver, Colo.; Mining Eng. August, 1896.

George Hall Ashley, M. E., Ph. D., Charleston, S. C.; Professor of Natural History, College of Charleston. August, 1896.

Harry Foster Bain, M. S., Des Moines, Iowa; Assistant Geologist, Iowa Geological Survey. December, 1895.

Rufus Mather Bagg, Ph. D., Colorado College, Colorado Springs, Colo. December, 1896.

S. Prentiss Baldwin, 1345 Euclid Ave., Cleveland, Ohio. August, 1895.

Erwin Hinckley Barbour, Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

George H. Barton, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

Florence Bascom, Ph. D., Bryn Mawr, Pa.; Instructor in Geology, Petrography, and Mineralogy in Bryn Mawr College. August, 1894.

William S. Bayley, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

*George F. Becker, Ph. D., Washington, D. C.; U. S. Geological Survey.

Charles E. Beecher, Ph. D., Yale University, New Haven, Conn. May, 1889.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

Samuel Walker Beyer, Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

Albert S. Bickmore, Ph. D., American Museum of Natural History, New York; Professor in charge Department of Public Instruction. December, 1889.

Irving P. Bishop, 109 Norwood Ave., Buffalo, N. Y.; Professor of Natural Science, State Normal and Training School. December, 1899.

Emilio Böse, Ph. D., Calle del Paseo Nuevo, no. 2, Mexico, D. F.; Geologist of the Instituto Geologico de Mexico. December, 1899.

*John C. Branner, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford Jr. University.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

*Garland C. Broadhead, Columbia, Mo.; Professor of Geology in the University of Missouri.

Alfred Hulse Brooks, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1899.

*SAMUEL CALVIN, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa. State Geologist.

HENRY DONALD CAMPBELL, Ph. D., Lexington Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

MARIUS R. CAMPBELL, U. S. Geological Survey, Washington, D. C. August, 1892.

FRANKLIN R. CARPENTER, Ph. D. Deadwood, South Dakota; Superintendent Deadwood and Delaware Smelting Company. May, 1889.

*T. C. CHAMBERLIN, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

CLARENCE RAYMOND CLAGHORN, B. S. M. E., Vintondale, Pa. August, 1891.

* WILLIAM BULLOCK CLARK, Ph. D., Baltimore, Md., Professor of Geology in Johns Hopkins University; State Geologist.

JOHN MASON CLARKE, A. M., Albany, N. Y., State Paleontologist. December, 1897.

* EDWARD W. CLAYPOLE, D. Sc., Pasadena, Cal.

J. MORGAN CLEMENTS, Ph. D., Madison, Wis.; Assistant Professor of Geology in University of Wisconsin. December, 1894.

COLLIER COBB, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

ARTHUR P. COLEMAN, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

GEORGE L. COLLIE, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

*THEODORE B. COMSTOCK, Los Angeles, Cal.; Mining Engineer.

* FRANCIS W. CRAGIN, Ph. D., Colorado Springs, Colo.; Professor of Geology in Colorado College.

* ALBERT R. CRANDALL, A. M., Alfred, N. Y.

ALJA ROBINSON CROOK, Ph. D., Evanston, Ill.; Professor of Mineralogy and Petrography in Northwestern University. December, 1898.

* WILLIAM O. CROSBY, B. S., Boston Society of Natural History, Boston, Mass.; Asst. Prof. of Mineralogy and Lithology in Massachusetts Inst. of Technology.

WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

GARRY E. CULVER, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

* HENRY P. CUSHING, M. S., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

*NELSON H. DARTON, United States Geological Survey, Washington, D. C.

* WILLIAM M. DAVIS, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

GEORGE M. DAWSON, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Canada; Director of Geological and Natural History Survey of Canada. May, 1889.

DAVID T. DAY, Ph. D., U. S. Geol. Survey, Washington, D. C. August, 1891.

ORVILLE A. DERBY, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil. December, 1890.

*JOSEPH S. DILLER, B. S., United States Geological Survey, Washington, D. C.

EDWARD V. D'INVILLIERS, E. M., 711 Walnut St., Philadelphia, Pa. Dec., 1888.

RICHARD E. DODGE, A. M., Teachers' College, West 120th St., New York city; Professor of Geography in the Teachers' College. August, 1897.

NOAH FIELDS DRAKE, Ph. D., Tientsin, China; Professor of Geology in Imperial Tientsin University. December, 1898.

CHARLES R. DRYER, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

* EDWIN T. DUMBLE, Austin, Texas; State Geologist.

CLARENCE E. DUTTON, Major U. S. A., Ordnance Department, Washington, D. C. August, 1891.

* WILLIAM B. DWIGHT, Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

ARTHUR S. EAKLE, Ph. D., Berkeley, Cal.; Instructor in Mineralogy, University of California. December, 1899.

CHARLES R. EASTMAN, A. M., Ph. D., Cambridge, Mass.; Assistant in Paleontology in Harvard University. December, 1895.

* GEORGE H. ELDRIDGE, A. B., United States Geological Survey, Washington, D. C.

ARTHUR H. ELFTMAN, Ph. D., Grand Marais, Minn. December, 1898.

ROBERT W. ELLS, LL. D., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. December, 1888.

* BENJAMIN K. EMERSON, Ph. D., Amherst, Mass.; Professor in Amherst College.

* SAMUEL F. EMMONS, A. M., E. M., U. S. Geological Survey, Washington, D. C.

JOHN EYERMAN, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

HAROLD W. FAIRBANKS, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

* HERMAN L. FAIRCHILD, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

J. C. FALES, Danville, Kentucky; Professor in Centre College. December, 1888.

OLIVER C. FARRINGTON, Ph. D., Chicago, Ill.; In charge of Department of Geology, Field Columbian Museum. December, 1895.

AUGUST F. FOERSTE, Ph. D., 417 Grand Ave., Dayton, Ohio, Teacher of Sciences. December, 1899.

WILLIAM M. FONTAINE, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* PERSIFOR FRAZER, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.

* HOMER T. FULLER, Ph. D., Springfield, Mo.; President of Drury College.

MYRON LESLIE FULLER, S. B., U. S. Geological Survey, Washington, D. C. December, 1898.

HENRY STEWART GANE, Ph. D., 116 Market St., Chicago, Ill. December, 1896.

HENRY GANNETT, S. B , A. Met. B., U. S. Geological Survey, Washington, D. C. December, 1891.

* GROVE K. GILBERT, A. M., LL. D., U. S. Geological Survey, Washington, D. C.

ADAM CAPEN GILL, Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

CHARLES H. GORDON, Ph. D., Lincoln, Neb.; Superintendent of Schools. August, 1893.

AMADEUS WILLIAM GRABAU, S. B., Cambridge, Mass.; Fellow in Paleontology, Harvard University. December, 1898.

ULYSSES SHERMAN GRANT, Ph. D., Evanston, Ill.; Professor of Geology, Northwestern University. December, 1890.

WILLIAM STUKELEY GRESLEY, Erie, Pa.; Mining Engineer. December, 1893.

GEORGE P. GRIMSLEY, Ph. D., Topeka, Kan.; Professor of Geology in Washbuan College. August, 1895.

LEON S. GRISWOLD, A. B., 238 Boston St., Dorchester, Mass. August, 1892.

FREDERIC P. GULLIVER, Ph. D., St. Mark's School, Southboro, Mass. August, 1895.

ARNOLD HAGUE, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

*Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

John B. Hastings, M. E., Rossland, British Columbia. May, 1889.

John B. Hatcher, Ph. B., Carnegie Museum, Pittsburgh, Pa. August, 1895.

*Erasmus Haworth, Ph. D., Lawrence, Kan.; Professor of Geology, University of Kansas.

C. Willard Hayes, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

*Angelo Heilprin, Academy of Natural Sciences, Philadelphia, Pa; Professor of Paleontology in the Academy of Natural Sciences.

*Eugene W. Hilgard, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

*Robert T. Hill, B. S., U. S. Geological Survey, Washington, D. C.

Richard C. Hills, Mining Engineer, Denver, Colo. August, 1894.

*Charles H. Hitchcock, Ph. D., LL. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

William Herbert Hobbs, Ph. D., Madison, Wis.; Assistant Professor of Mineralogy in the University of Wisconsin. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York city.

Arthur Hollick, Ph. B., Columbia University, New York; Instructor in Geology. August, 1893.

*Joseph A. Holmes, Chapel Hill, N. C.; State Geologist and Professor of Geology in University of North Carolina.

Thomas C. Hopkins, Ph. D., Syracuse, N. Y.; Instructor in Geology, Syracuse University. December, 1894.

*Edmund Otis Hovey, Ph. D., American Museum of Natural History, New York city; Assistant Curator of Geology.

*Horace C. Hovey, D. D., Newburyport, Mass.

*Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich.; State Geologist of Michigan. December, 1894.

*Alpheus Hyatt, B. S., Boston Society of Natural History, Boston, Mass.; Curator of Boston Society of Natural History.

Joseph P. Iddings, Ph. B., Professor of Petrographic Geology, University of Chicago, Chicago, Ill. May, 1889.

A. Wendell Jackson, Ph. B., 407 St. Nicholas Ave., New York city. Dec., 1888.

Robert T. Jackson, S. D., 9 Fayerweather St., Cambridge, Mass.; Instructor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

*Willard D. Johnson, United States Geological Survey, Washington, D. C.

Alexis A. Julien, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

Arthur Keith, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

*James F. Kemp, A. B., E. M., Columbia University, New York city; Professor of Geology.

Charles Rollin Keyes, Ph. D., 944 Fifth St., Des Moines, Iowa. August, 1890.

Wilbur C. Knight, B. S., A. M., Laramie, Wyo.; Professor of Mining and Geology in the University of Wyoming. August, 1897.

Frank H. Knowlton, M. S., Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. May, 1889.

HENRY B. KÜMMEL, Ph. D., Trenton, N. J.; Assistant State Geologist. December, 1895.

* GEORGE F. KUNZ, care of Tiffany & Co., 15 Union Square, New York city.

RALPH D. LACOE, Pittston, Pa. December, 1889.

GEORGE EDGAR LADD, Ph. D., Rolla, Mo.; Director School of Mines. August, 1891.

J. C. K. LAFLAMME, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

ALFRED C. LANE, Ph. D., Lansing, Mich.; Assistant State Geologist. Dec., 1889.

DANIEL W. LANGTON, Ph. D., 39 East Tenth St., New York city; Mining Engineer. December, 1889.

ANDREW C. LAWSON, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

* JOSEPH LE CONTE, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

* J. PETER LESLEY, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

FRANK LEVERETT, B. S., Denmark, Iowa; Asst., U. S. Geol. Survey. Aug., 1890.

WILLIAM LIBBEY, Sc. D., Princeton, N. J.; Professor of Physical Geography in Princeton University. August, 1899.

WALDEMAR LINDGREN, U. S. Geological Survey, Washington, D. C. August, 1890.

ROBERT H. LOUGHRIDGE, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

ALBERT P. LOW, B. S., Geological Survey Office, Ottawa, Canada; Geologist on Canadian Geological Survey. August, 1892.

THOMAS H. MACBRIDE, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

HENRY MCCALLEY, A. M., C. E., University, Tuscaloosa county, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

RICHARD G. MCCONNELL, A. B., Geological Survey Office, Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

JAMES RIEMAN MACFARLANE, A. B., 100 Diamond St., Pittsburg, Pa. August, 1891.

* W J MCGEE, Washington, D. C.; Bureau of North American Ethnology.

WILLIAM MCINNES, A. B., Geological Survey Office, Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

PETER MCKELLAR, Fort William, Ontario, Canada. August, 1890.

CYRUS F. MARBUT, A. M., State University, Columbia, Mo.; Instructor in Geology and Assistant on Missouri Geological Survey. August, 1897.

VERNON F. MARSTERS, A. M., Bloomington, Ind.; Professor of Geology in Indiana State University. August, 1892.

EDWARD B. MATHEWS, Ph. D., Baltimore, Md.; Instructor in Petrography in Johns Hopkins University. August, 1895.

P. H. MELL, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

JOHN C. MERRIAM, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

* FREDERICK J. H. MERRILL, Ph. D., State Museum, Albany, N. Y.; Assistant State Geologist and Assistant Director of State Museum.

GEORGE P. MERRILL, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

ARTHUR M. MILLER, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

James E. Mills, B. S., Quincy, Plumas Co., Cal. December, 1888.
Thomas F. Moses, M. D., Worcester Lane, Waltham, Mass. May, 1889.
* Frank L. Nason, A. B., West Haven, Conn.
* Peter Neff, A. M., 361 Russell Ave., Cleveland, Ohio; Librarian, Western Reserve Historical Society.
Frederick H. Newell, B. S., U. S. Geol. Survey, Washington, D. C. May, 1889.
John F. Newsom, A. M., Stanford University, Cal.; Associate Professor of Metallurgy and Mining. December, 1899.
William H. Niles, Ph. B., M. A., Cambridge, Mass. August, 1891.
William H. Norton, M. A., Mt. Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.
Charles J. Norwood, Mining Engineer; St. Bernard Coal Co., Earlington, Ky. August, 1894.
Ezequiel Ordonez, Esquela N. de Ingeneiros, City of Mexico, Mexico; Geologist del Instituto Geologico de Mexico. August, 1896.
* Amos O. Osborn, Waterville, Oneida Co., N. Y.
Henry F. Osborn, Sc. D., Columbia University, New York city; Professor of Zoology, Columbia University. August, 1894.
Charles Palache, B. S., University Museum, Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1897.
* Horace B. Patton, Ph. D., Golden, Colo.; Professor of Geology and Mineralogy in Colorado School of Mines.
Samuel L. Penfield, Ph. B., M. A., New Haven, Conn.; Professor of Mineralogy, Sheffield Scientific School of Yale University. December, 1899.
Richard A. F. Penrose, Jr., Ph. D., 1331 Spruce St., Philadelphia, Pa. May, 1889.
Joseph H. Perry, 176 Highland St., Worcester, Mass. December, 1888.
* William H. Pettee, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology, and Mining Engineering in Michigan University.
Louis V. Pirsson, Ph. D., New Haven, Conn.; Assistant Professor of Inorganic Geology, Sheffield Scientific School. August, 1894.
* Franklin Platt, 1617 Chestnut St., Philadelphia, Pa.
* Julius Pohlman, M. D., University of Buffalo, Buffalo, N. Y.
John Bonsall Porter, E. M., Ph. D., Montreal, Canada; Professor of Mining, McGill University. December, 1896.
* John W. Powell, Bureau of Ethnology, Washington, D. C.
Joseph Hyde Pratt, Ph. D., Chapel Hill, N. C.; Assistant Geologist, North Carolina Geological Survey. December, 1898.
* Charles S. Prosser, M. S., Columbus, Ohio; Associate Professor of Historical Geology in Ohio State University.
* Raphael Pumpelly, U. S. Geological Survey, Dublin, N. H.
Edmund C. Quereau, Ph. D., Aurora, Ill. August, 1897.
Frederick Leslie Ransome, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.
Harry Fielding Reid, Ph. D., Johns Hopkins Univ., Baltimore, Md. Dec., 1892.
William North Rice, Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.
Charles H. Richardson, Ph. D., Hanover, N. H.; Instructor in Chemistry and Mineralogy, Dartmouth College. December, 1899.
Heinrich Ries, Ph. D., Cornell University, Ithaca, N. Y.; Instructor in Economic Geology. December, 1893.

Charles W. Rolfe, M. S., 601 John St., Champaign, Ill.; Professor of Geology in University of Illinois. May, 1889.

*Israel C. Russell, LL. D., Ann Arbor, Mich.; Professor of Geology in University of Michigan.

*James M. Safford, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.

Orestes H. St. John, Raton, N. Mex. May, 1889.

* Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, Ph. D., Instructor in Paleontology, University of Minnesota, Minneapolis, Minn. December, 1892.

*Charles Schaeffer, M. D., 1309 Arch St., Philadelphia, Pa.

Charles Schuchert, Washington, D. C.; Assistant Curator in Paleontology, U. S. National Museum. August, 1895.

William B. Scott, Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in College of New Jersey. August, 1892.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

*Nathaniel S. Shaler, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.

George Burbank Shattuck, Ph. D., Baltimore, Md.; Associate Professor in Physiographic Geology, Johns Hopkins University. August, 1899.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal Sch. Dec., 1890.

* Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

*Eugene A. Smith, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

Frank Clemes Smith, B. S., Deadwood, S. Dak.; Mining Engineer. Dec., 1898.

George Otis Smith, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1897.

*John C. Smock, Ph. D., Trenton, N. J.; State Geologist.

Charles H. Smyth, Jr., Ph. D., Clinton, N. Y.; Professor of Geology in Hamilton College. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Instructor in Mining Geology in Harvard University. August, 1894.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

*J. W. Spencer, Ph. D., 152 Bloor St. East, Toronto, Canada.

Josiah E. Spurr, A. B., A. M., U. S. Geol. Survey, Washington, D. C. Dec., 1894.

Joseph Stanley-Brown, 1318 Massachusetts Ave., Washington, D. C. August, 1892.

Timothy William Stanton, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

*John J. Stevenson, Ph. D., LL. D., New York University; Professor of Geology in the New York University.

Joseph A. Taff, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1895.

James E. Talmage, Ph. D , Salt Lake City, Utah; Professor of Geology in University of Utah. December, 1897.

Ralph S. Tarr, Cornell University, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography. August, 1890.

Frank B. Taylor, Fort Wayne, Ind. December, 1895.

William G. Tight, M. S., Granville, Ohio; Professor of Geology and Biology, Denison University. August, 1897.

* James E. Todd, A. M., Vermilion, S. Dak.; Professor of Geology and Mineralogy in University of South Dakota.

* Henry W. Turner, B. S., U. S. Geological Survey, San Francisco, Cal.

Joseph B. Tyrrell, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.

Johan A. Udden, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College, August, 1897.

* Warren Upham, A. M., Librarian Minnesota Historical Society, St. Paul, Minn.

* Charles R. Van Hise, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist, U. S. Geological Survey.

Frank Robertson Van Horn, Ph. D., Cleveland, Ohio; Instructor in Geology and Mineralogy, Case School of Applied Science. December, 1898.

Thomas Wayland Vaughan, B. S., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

* Anthony W. Vogdes, Fort Wadsworth, Staten Island, N. Y.; Captain Fifth Artillery, U. S. Army.

* Marshman E. Wadsworth, Ph. D., Box 296, Chicago, Ill.

* Charles D. Walcott, U. S. National Museum, Washington, D. C.; Director U. S. Geological Survey.

Henry Stephens Washington, Ph. D., Locust, Monmouth Co., N. J. August, 1896.

Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

Lewis G. Westgate, Ph. D., Delaware, Ohio; Professor of Geology, Ohio Wesleyan University.

Thomas C. Weston, Ottawa, Canada. August, 1893.

David White, U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey, Washington, D. C. May, 1889.

* Israel C. White, Ph. D., Morgantown, W. Va.

Theodore Greely White, Ph. B., A. M., New York city; Assistant in Physics, Columbia University. December, 1898.

* Robert P. Whitfield, Ph. D., American Museum of Natural History, 78th St. and Eighth Ave., New York city; Curator of Geology and Paleontology.

* Edward H. Williams, Jr., A. C., E M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

* Henry S. Williams, Ph. D., New Haven, Conn.; Professor of Geology and Paleontology in Yale University.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

Samuel Wendell Williston, Ph. D., M. D., Lawrence, Kan.; Professor of Historical Geology, University of Kansas. December, 1898.

Arthur B. Willmott, M. A., Toronto, Canada; Professor of Geology and Chemistry, McMaster University. December, 1899.

* Horace Vaughn Winchell, Butte, Montana; Geologist of the Anaconda Copper Mining Company.

* Newton H. Winchell, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

* Arthur Winslow, B. S., care of Missouri, Kansas and Texas Trust Company, Kansas City, Mo.

John E. Wolff, Ph. D., Harvard University, Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

Robert Simpson Woodward, C. E., Columbia College, New York city; Professor of Mechanics in Columbia College. May, 1889.

Jay B. Woodworth, B. S., 27 Dana St., Cambridge, Mass.; Instructor in Harvard University. December, 1895.

Albert A. Wright, Ph. D., Oberlin, Ohio; Professor of Geology in Oberlin College. August, 1893.

* G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

William S. Yeates, A. B., A. M., Atlanta, Ga.; State Geologist of Ga. Aug., 1894.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

* Charles A. Ashburner, M. S., C. E. Died December 24, 1889.
Amos Bowman. Died June 18, 1894.
* J. H. Chapin, Ph. D. Died March 14, 1892.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
* Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio del Castillo. Died October 28, 1895.
* James D. Dana, LL. D. Died April 14, 1895.
Sir J. William Dawson, LL. D. Died November 19, 1899.
* Albert E. Foote. Died October 10, 1895.
N. J. Giroux, C. E. Died November 30, 1896.
* James Hall, LL. D. Died August 7, 1898.
* Robert Hay. Died December 14, 1895.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
* Joseph F. James, M. S. Died March 29, 1897.
Oliver Marcy, LL. D. Died March 19, 1899.
Othniel C. Marsh, Ph. D., LL. D. Died March 18, 1899.
* Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
* John S. Newberry, M. D., LL. D. Died December 7, 1892.
* Edward Orton, Ph. D., LL. D. Died October 16, 1899.
* Richard Owen, LL. D. Died March 24, 1890
Charles Wachsmuth. Died February 7, 1896.
* George H. Williams, Ph. D. Died July 12, 1894.
* J. Francis Williams, Ph. D. Died November 9, 1891.
* Alexander Winchell, LL. D. Died February 19, 1891.

Summary.

Original Fellows	78
Elected Fellows	167
Membership	245
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